8-6-2021

Pen size and BRD: Impacts on antimicrobial use, antimicrobial resistance, performance, and profitability

Kirsten Midkiff
diamondlcattle3.kam@gmail.com

Pen size and BRD: Impacts on antimicrobial use, antimicrobial resistance, performance, and profitability

By

Kirsten Midkiff

Approved by:

Brandi B. Karisch (Major Professor)
Joshua G. Maples (Minor Professor)
Amelia R. Woolums
Trent Smith
Jamie Larson (Graduate Coordinator)
Scott Willard (Dean, College of Agriculture and Life Sciences)

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Agriculture
in the Department of Animal and Dairy Sciences

Mississippi State, Mississippi

August 2021

Name: Kirsten Midkiff

Date of Degree: August 6, 2021

Institution: Mississippi State University

Major Field: Agriculture

Major Professor: Brandi B. Karisch

Title of Study: Pen size and BRD: Impacts on antimicrobial use, antimicrobial resistance, performance, and profitability

Pages in Study: 69

Candidate for Degree of Master of Science

The objectives of this study were to evaluate the effect of number of stocker cattle in receiving pens (large: n=150 cattle; small: n=50 cattle) on 1) BRD morbidity/mortality, and performance, 2) antimicrobial use and prevalence of antimicrobial resistance in *Mannheimia haemolytica*, and 3) profitability of stocker operations. No differences were found for morbidity (p=0.5041). Mortality tended (p=0.0744) to be higher in large groups. BW increased (p<0.0001) over time. A treatment*day interaction (p=0.00592) was found for ADG, with largest gains for both groups from day 14-28. *M. haemolytica* recovery decreased (p=0.0002) over time. Antimicrobial resistance (p=0.0179) and MDR (p=0.0405) were higher in the small group. Treatment costs were higher in the small group ($1,093.53/hd) compared to large ($1,037.04/hd). Because of the nature of a pilot study, further research are needed to determine the effectiveness of reducing animals in a pen on health, growth, AMR, and profitability associated with stocker cattle.

DEDICATION

Nana, you are missed more than you can ever imagine. I could not have accomplished any of this without you looking out for me up in Heaven. I know I was not able to be there as often as I wanted to, especially moving so far away from home. For two years I was eleven hours from home and only able to come home for holidays; but it was not until I came six and a half hours away when your health started deteriorating. I never expected my first semester here at Mississippi State that you would end up in the hospital, when I would travel home every weekend for a month and a half to see you regardless of your health. My one regret- the one weekend I could have come home, the weekend before Thanksgiving, I should have gone home to see you. I will always thank Dr. Dinh for being so understanding of my situation and letting me makeup my test after Thanksgiving break so I could go be with you after you passed. I made you a promise the day of your funeral that I was going to finish my degree, that I did not spend all this time away from home for nothing, and I told you I was going all the way. I meant every word, and I hope you were able to carry that note with you as you walked through those pearly gates. I hope that I am making you proud down here, completing what I told you I was going to do. I cannot wait to see you again. I love you so much. This is for you.

ACKNOWLEDGEMENTS

To my major professor, Dr. Brandi Karisch, your mentorship and time that you have given me to do this project has truly opened my eyes to a world of the beef cattle industry that I was not familiar with. The opportunities and relationships that I have been able to build while under your wing has given me so much, and I will forever be grateful. To my committee- Dr. Amelia Woolums, Dr. Josh Maples, and Dr. Trent Smith- the fields that I was able to learn more of, the disciplines and knowledge that I have gained, and the role models that you are to me, have opened my eyes in more ways than one. Thank you for being a part of my journey. To each of you, I am forever grateful.

Thank you to the professors, the graduate students, others who have been there in one way or another. Here at the end, I gained an incredible support system in my grad student family that I cannot thank enough. Maggie Loftin, Arminda James, Kate DeShazo, Michelle Fenstermaker, Allison Harmon- you each will do amazing things in life. I am so blessed to call you my friends. I would not have been able to complete this project without the help of the farm crew, William White, Cody Glenn, and Corey White, and my incredible pen riders "Peanut", Charlie, Cord, and Jake. Without each of you, I would never have been able to keep the hair on my head, nor the memories that I have. It will be a time that I will cherish forever. I am incredibly thankful to Johnny Treichel, Brett Crow, and Tucker Wagner for funneling a love for livestock judging to me and giving me a chance to prove myself both on the team and as assistant coach. It was an amazing journey, and I thoroughly enjoyed it all.

This list gets extremely long, but if I did not detail it all I would not be acknowledging everyone who had a hand in pushing me through. Shannon and Lezlie, my Dad and Mom- thank you for all of your love and support throughout the many years I have been in school. Every phone call, motivational speech, and visit made life away from home much easier. It has been so hard being away for so many things, and your words lifted me to push through. To my brother Kagen- I look up to you more than you will ever be able to realize. Thank you for always pushing me to be my better self, and for giving me a hard time when I needed it. Watching you grow up and being your older sister has been a privilege and a huge roller coaster- one that I will always want to ride. To Hunter, you have helped me through the past two years more than you will ever know. You kept me on my toes, you pushed my knowledge on any subject, and have taught me so much. I will be forever grateful to have you as a friend, a partner, and a mentor. I will be forever grateful that Brett Crow introduced the two of us, because without you I do not know how I could have got through this all. Pawpaw and Grandmama- you have always been there to extend a loving arm when it was needed. I cannot be more thankful for the many days that I was able to be with you either in the hay field, working cows, or just sitting inside talking. Aunt Shanda and Uncle Ricky- you have opened your home and your horses to me, let me come over and enjoy your company over the holidays when I needed it most, gave me a seat in the truck to go to barrel races and to the racetracks to watch you compete. You have been there more times than not, and I am so blessed to have you both in my life. To my friends, my "people," who were there for a late-night phone call, study session, break down, or anything in between- Kyle Fitch, Allyn Garrett, Carley Greer, Kerrigan Meaux, Amber Coker, Dr. Michael Meaux, Kim Meaux, Valari Rutherford, Dr. Courtney Heaton, Alicia Gilmore, Sarah Montgomery, Allie Nestor, Kayla Higgs- thank you for helping me in more ways you will ever know. To those not

mentioned because I have a horrible memory and the list of people is so long, my extended family in Texas and elsewhere, thank you for being my biggest supporters. You may not be listed definitively, but you will forever be in my heart.

My time at Mississippi State may be coming to an end, but the memories and the list of people to thank are too long to even fathom. I have forgotten so many to place here but have not forgotten what you have done for me personally. Thank you. As always, Hail State and Go Dawgs!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

ADG	Average Daily Gain
BW	Body Weight
BRD	Bovine Respiratory Disease
PI	Persistently Infected
AMR	Antimicrobial Resistance
MDR	Multidrug Resistance
BVDV	Bovine Viral Diarrhea Virus
AMP	Ampicillin
CEF	Ceftiofur
PEN	Penicillin
DAN	Danofloxacin
ENRO	Enrofloxacin
GM	Gamithromycin
TDP	Tildipirosin
TIL	Tilmicosin
TUL	Tulathromycin
TET	Tetracycline
SPE	Spectinomycin
FLR	Florfenicol

CHAPTER I

INTRODUCTION

The beef production system includes several phases which cattle transition through during their lifetime, and forage-based systems dominate these phases. However, the nature of the system exposes cattle to multiple stressors that increase respiratory disease risk. Historically antimicrobials have been a major tool for controlling BRD, but emergence of antimicrobial resistance indicates this may not be sustainable. Reducing the number of animals in a pen is a simple management practice that may impact BRD transmission, and in turn decrease antimicrobial use and antimicrobial resistance. With some consumers demanding beef raised in a system with no antimicrobial use, validation of management practices to keep cattle healthy with less antimicrobial use is vital to improving the productivity, profitability, and sustainability of beef systems. The effect of pen size on BRD morbidity and antimicrobial resistance in forage-based stocker cattle has not been investigated.

Ninety percent of U.S. cow-calf operations have fewer than 100 cattle, with these operations representing 46% of the U.S. beef cow inventory (USDA, NASS 2007 Census of Agriculture). Calves from cow-calf operations will be utilized for beef after being fed in a feedlot. Before entering the feedlot, calves are often placed on pastures to allow time for added growth and immune development. Stockering not only helps calves prepare to efficiently mature into healthy feedlot cattle, it also provides farmers with a low-overhead source of income based on seasonal availability of forage (Rankins and Prevatt, 2013; Rhinehart and Poore, 2013; Horn, 2006). However, the transportation and commingling inherent in this system predisposes stocker cattle to bovine respiratory disease (BRD), the leading cause of sickness and death in stocker and feedlot operations (Sweiger and Nichols, 2010).

Stockering newly weaned cattle has become an important market for the livestock industry. The stocker industry adds value to cattle by allowing time for building immunity, improving the nutrition plane of younger cattle, adding growth and weight to lighter calves, and providing feedlots with a higher quality calf (Peel, 2003). The building of immunity is important in "high risk" cattle, as the stressors of weaning, environmental changes, and management practices that have not been performed by producers (i.e. castration, vaccination, deworming) can affect the immune system. Profitability becomes key for stocker operations, as the commingling of cattle from unknown origin and managements allows for increased possibility of morbidity and mortality.

With high-risk, newly weaned stocker calves comes increased problems with diseases and sickness. Locating and purchasing of cattle in different markets, the ability to optimize on forages and inputs in pastures and pens, management and facilities, cattle performance, and ultimately profitability of the operation are all determined by the ability to maintain healthy cattle (Sweiger and Nichols, 2010). As the risk of morbidity and mortality increases, the cost of disease control (drug costs) increases, so it is important to keep a strong immune system to decrease the rate of disease (Edwards, 2010).

Cattle with sickness are typically treated with antimicrobials, which have been widely used to treat and prevent BRD outbreaks. However, recent reports have shown antimicrobial resistance among many classes of antimicrobials and bacterial organisms most commonly associated with BRD cases. Specifically, high levels of resistance have been reported for

Mannheimia haemolytica, Pasteurella multocida, and *Histophillus somni*, in particular oxytetracycline, tulathromycin, and penicillin (Timsit et al., 2017). *Mannheimia haemolytica* has been most associated with BRD in stocker and feedlot cattle (Step et al., 2007; Nickell and White, 2010). Management practices that ensure stocker health while decreasing reliance on antimicrobials should improve sustainability of U.S. cattle operations.

Within cattle herds, sickness has been known to travel from animal to animal in a variety of ways, the most common being nose-to-nose contact. Antimicrobial usage in single animals has been shown to increase the risk of isolating susceptible and MDR *M. haemolytica* from pen mates (Noyes, 2015). It may be possible that reducing the number of animals in a pen could decrease the incidence of morbidity, antimicrobial use, and antimicrobial resistance. If smaller stocker cattle groups require less antimicrobial treatment for BRD, producers could have a validated tool to maintain stocker health and decrease antimicrobial use.

Bovine respiratory disease encompasses a vital portion of economic losses in the beef cattle industry in both stocker and feedlot operations. In 2015, economic loss from cattle that succumbed respiratory disease was $907.8 million, or 24.6%, of the total value of nonpredator death losses in cattle and calves (USDA, 2017). Because of difficulty of collecting data and records, most of the economic data that is used today comes from feedlot operations.

At the feedlot and backgrounding facility, respiratory disease impacts include mortality (death loss values), reduce weight gain, reduced feed efficiency, reduced salvage value of chronic animals, treatment costs, vaccination costs, and metaphylaxis costs (Peel, 2020). Over the years, the costs of antimicrobial treatments, decreases in performance, and feedlot/stocker manager’s bottom line have influenced the need for management strategies that reduce antimicrobial use. Regardless of the situation, improving immune function is key to having a profitable animal, as immunity is the first line of defense when it comes to stocker cattle. However, it has yet to be discussed whether sorting cattle into smaller pens may reduce the incidence of respiratory disease. Because of the economic impacts of BRD despite continued developments in vaccinations and other technologies, this research focuses on the idea that reducing the number of cattle within a pen may impact the costs of respiratory disease to the stocker and feedlot operations. This study tests the impact of a simple husbandry practice, maintaining cattle in small groups, on BRD rates, antimicrobial use, antimicrobial resistance, and production costs.

CHAPTER II

LITERATURE REVIEW

Bovine Respiratory Disease

Bovine Respiratory Disease (BRD; also known as shipping fever) is the most costly disease in North America and is the leading cause of sickness and death in beef cattle (Griffin, 2007; Woolums et al., 2018). Bovine respiratory disease is a multifactorial disease usually caused by various predisposing factors. It is caused by a variety of pathogens, both viral and bacterial in addition to stressors that have weakened the immune system. Stressors that could lead to a weakened immune system can be weaning, changes in feed or nutrition, processing (castration, vaccination, deworming), and variations in climate (temperature and weather). Also, the complex generally occurs with viral agents, such as BVDV, being considered as precursors to, or occurring simultaneously with, bacterial infections (Cusack et al., 2003).

Case definition for diagnosing BRD varies greatly in the literature. General signs for cattle with BRD include, but are not limited to, an elevated body temperature of ≥40°C, various respiratory signs (nasal discharge, increased respiratory rate, or cough), anorexia, depression, and lethargy. Often, cases show a various combination of these signs or other secondary signs of illness (Taylor et al., 2010). Problems arise with diagnosing BRD, as cattle tend to disguise their signs from those observing the animals. Lung lesions were reported in 61.9% of cattle observed at slaughter, while 60.9% of those cattle were never diagnosed and treated for BRD (Schneider et al., 2009). This study highlights the true difficulty of identifying disease in cattle that appear healthy but are suffering from sickness.

Predisposing Factors for BRD

Local auction markets provide an important way for cattlemen to market their cattle. Performing an analysis of the marketing channels competing for stocker calves, Schmitz et al. (2003) estimates that roughly 66% of stocker cattle are marketed through public auction, 19% privately sold, 11% sold through video auction, and 5% marketed through internet sales. Trailers of low-managed cattle arriving to sale facilities with high-managed cattle, as well as the commingling among different cattle and stresses of weaning combined make auction barns a prime location for contracting pathogens. This, in combination with the stress of hauling to a new environment, suppresses immune function of cattle and allows for greater possibility of sickness, and the increased risk of contracting respiratory disease.

Depending on the type of management that cow-calf producers have, some weaned cattle may have never been processed before entering the sale barn. Processing entails vaccinating, deworming, and castrating the cattle prior to sale at an auction barn. Failing to process newly weaned cattle exposes them to increased risks for compromised immune system, especially when added stressors of shipping and commingling are factored in.

Viral agents can cause direct damage to respiratory clearance mechanisms and lung parenchyma, facilitating translocation of bacteria from the upper respiratory tract to establish infections in the lung (Taylor et al., 2012). Also, viral infection can interfere with the immune system's ability to respond to bacterial infection (Martin et al., 1986; Czuprynski et al., 2004). Common viral agents accounting for BRD infections include bovine herpesvirus 1 (BHV-1), parainfluenza virus type 3 (PI-3), bovine viral diarrhea virus (BVDV), and bovine respiratory syncytial virus (BRSV; Cusack et al., 2003). It has been shown that persistent infection (PI) with BVDV increases BRD occurrence, but it is unclear if PI calves affect other cattle in the feedlot (Taylor et al., 2010). Vaccinating and reducing the chances for viral agents to infect the animal could decrease BRD outbreaks and benefit the overall immunity of the herd.

Environmental factors that can affect animal health can include climate, stocking density, humidity, shipping distance, and ambient temperature (Snowder et al., 2006). Cernicchiaro et al. (2012) reported that distance travelled was significantly associated with BRD morbidity and mortality and concluded that knowing distance travelled could allow more precise prediction of cattle feedlot healthy and performance. Vast differences in weather can change the immune status of the animal, such as a moderate temperature and cloudy day changing to rain and freezing temperatures. All of these can affect animal health and possibly compromise the immune system.

Mannheimia haemolytica

The four bacteria that are most isolated from BRD cases are *Mannheimia haemolytica (M. haemolytica), Pasteurella multocida (P. multocida), Histophillus somni (H. somni),* and *Mycoplasma spp.* (Griffin, 1998; Fulton et al., 2009). Each bacterium is known to be indigenous to the nasopharyngeal passages, and, after stress or viral infection, can proliferate and be inhaled into the lungs (Panciera and Confer, 2010). It has been shown that *M. haemolytica* is the bacteria most common BRD bacteria isolated in stocker and feedlot cattle (Fulton et al., 2002; Step et al., 2007; Nickell and White, 2010; Woolums et al., 2018). Increased use of antimicrobials among the cattle industry segments has led to an increase in antimicrobial resistance among these different bacteria. The importance of the bacterial organism in terms of colonization, transmission dynamics to pen mates, antimicrobial resistance, and multidrug resistance, are major reasons for this research.

M. haemolytica, formally known as *Pasteurella haemolytica*, is a small gram-negative, facultatively anaerobic bacterium that expresses weak hemolysis on blood agar plates (sheep or bovine blood agar plates are typically used). The bacteria are normally indole negative, oxidase positive, and catalase positive. As well, it is a fermentative, nonmotile, and a non-spore-forming rod or coccobacillus (Griffin et al., 2010). The genus *Mannheimia* is part of the class α-Proteobacteria, order Pasteurellales, family Pasteurellaceae (Griffin et al., 2010). The *Mannheimia* genus is differentiated from *Pasteurella* by the fermentation of mannitol and failure to use d-mannose (Griffin et al., 2010), along with 16S rRNA sequence phylogeny and DNA-DNA hybridization (Zecchinon et al., 2005; Griffin et al., 2006). *M. haemolytica* can be defined by at least 12 capsular serotypes (1, 2, 5-9,12-14, 16, and 17), with serotype A1 being associated with >75% of clinical cases (Confer and Step, 2009).

Bacteria are often found in the nasopharynx of healthy cattle but have substantially more growth in morbid animals. *M.* haemolytica remains confined in the tonsillar crypts of the upper respiratory tract, primarily the nasopharynx. When cattle are stressed, the replication rate of the bacteria increases rapidly. The increased bacterial growth rate in the upper respiratory tract, followed by inhalation and colonization of the lungs, may occur because of immune suppression brought on by stressors or a viral infection. During growth in the lungs, virulence factors are produced. These virulence factors include the capsule, outer membrane proteins, adhesins, neuraminidase, endotoxin, and exotoxic leukotoxin (Jeyaseelan et al., 2002). The interaction between the virulence factors and host defenses results in tissue damage, with characteristic necrosis, thrombosis, and exudation, leading to the development of pneumonia. Recently, Cozens et al. (2019) found that the virulence determinants of *M. haemolytica* serotype A1 facilitate the invasion of the respiratory epithelial cells allowing for increased replication and spread to nearby cells where extensive damage to the lung tissues can occur. This, however, was not reported in other serotypes commensal to the respiratory tract (Cozens et al., 2019).

Nasopharyngeal swabs can be used for determination of colonization in the nasopharynx. This method of bacterial collection has proven to be quick, simple, and relatively non-invasive. Nasopharyngeal swabs have been used in varieties of studies to give researchers an idea of bacteria present and the degree of which bacteria colonization has occurred (Fulton et al., 2002; Jong et al., 2014; Timsit et al., 2017; Woolums et al., 2018), as well as being the recommended tool for studying antimicrobial susceptibility (DeRosa et al., 2000). The difficulty with nasopharyngeal swabs is that the swab may not contact the bacteria that researchers are studying. As well, bacterial colonies may be in one portion of the nasopharynx, where the swab may not be able to reach. Pass and Thompson (1971) reported that *M. haemolytica* were present on the surface of the nasal epithelium, and that while a bacterial culture revealed that there was no *M. haemolytica* isolated from a nasal swab culture it did not mean that *M. haemolytica* was absent from the nasopharynx. Similarly, Capik et al. (2015) determined that there were fluctuations in the pattern of *M. haemolytica* shedding and the ability to recover *M. haemolytica* from a culture swab to show the true representation of bacterial presence in the animal.

Understanding transmission dynamics of *M. haemolytica* is needed to adapt control measures during BRD episodes (Miles, 2009). Little information is known about the transmission dynamics of *M. haemolytica*. It is not clear whether *M. haemolytica* associated BRD cases are due to predisposing factors that enable the resident flora to overcome the cattle's immune system or due the contagious spread of a single virulent clone among pen mates, or due to both (Rice et al., 2007; Taylor et al., 2010). Timsit et al. (2013) reported that isolation of *M. haemolytica* was confirmed on 14/16 BRD episodes, with two to three different clones reported for ten episodes and only one clone recovered in four episodes. The significant within-pen diversity of *M. haemolytica* during BRD episodes indicates that disease is not primarily due to the spread of a single virulent clone among cattle (Timsit et al., 2013). These reports concluded that more research needs to be performed on transmission dynamics to enable more coherent understanding the transfer of *M. haemolytica* from calf to calf.

Antimicrobial Resistance Across BRD Causative Agents

Historically, antimicrobials have been an effective tool for controlling BRD. Stocker operations rely on antimicrobials to control disease outbreaks in cattle, overall allowing for animals to become healthy at a faster rate and decreasing the duration of periods of little to no growth. The typical administration of antimicrobials can be divided up into three practices, including 1) prophylaxis, 2) metaphylaxis, and 3) growth promotion (Cameron and McAllister, 2016), with growth promotion no longer allowed in production settings. Unfortunately, these practices are described very inconsistently in literature. For example, the American Veterinary Medical Association and US Food and Drug Administration describe prophylaxis and metaphylaxis as therapeutic, while others may consider these to be sub-therapeutic, non-therapeutic, or production usage (American Veterinary Medical Association, 1998; McEwen and Fedorka-Cray, 2002; Center for Veterinary Medicine, US Food and Drug Administration). Today, antimicrobials are typically given either therapeutically for prophylaxis, metaphylaxis, or for treating diseases. Regardless of the route taken to improve livestock health, bacterial resistance that is acquired in response to antimicrobial usage has damaged future efficacy of these antimicrobials, due to the AMR genes that are linked in clusters, leading to the multidrug resistant (MDR) organisms (Cameron and McAllister, 2016). Even with this, the difficulty with diagnosing how the problem of antimicrobial resistance came to be lies in three main arguments: 1) most antimicrobials are approved for use in multiple food-animal species; 2) off-label non-intended usage of antimicrobials is a common practice worldwide; and 3) the antimicrobial may not have been administered to the animal (Cameron and McAllister, 2016). Lingering questions still remain on where the true beginning of antimicrobial resistance lies but the best routes for controlling the spread of the AMR bacteria are an important topic among research.

Recent reports show high rates of antimicrobial resistance found among bacteria for multiple antimicrobial classes. Timsit et al. (2017) discovered high levels of resistance to tulathromycin, oxytetracycline, and penicillin among *M. haemolytica, P. multocida, and H. somni*. This brings forth more difficulty in determining practices that reduce the incidence of BRD among cattle to decrease the prevalence of antimicrobial resistance and multidrug resistant (MDR) bacteria. Researchers show MDR isolates from lung tissue of fatal BRD cases and suggest that prevalence of MDR bacteria is increasing. Booker et al. (2008) examined microbiological and histopathological findings in fatal BRD cases from Canadian feedlots. This study utilized diagnostic developments, such as immunohistochemical (IHC) staining, and histopathologic examination to allow for a more sensitive, descriptive collection of data that previous studies had not utilized prior. Researchers concluded that both *Mannheimia haemolytica* and *Mycoplasma bovis* were the most isolated bacterial organisms, with *M. haemolytica* most predominant in peracute, acute, and subacute cases (Booker et al., 2008). Lubbers and Hazlicek (2013) conducted a retrospective analysis from 2009 to 2011 to determine antimicrobial multidrug resistance and coresistance patterns among *M. haemolytica* isolated from BRD cases for antimicrobials ceftiofur, enrofloxacin, florfenicol, oxytetracycline, spectinomycin, and tilmicosin. By 2011, 82.7% of isolates were resistant to at least one antimicrobial. Further, in 2009 approximately 35% of *M. haemolytica* isolates were pan-susceptible (susceptible to all six antimicrobials tested) with resistance to 1, 2, 3, 4, and 5 antimicrobials being 9%, 15%, 13%, 24%, and 5%, respectively, among *M. haemolytica* isolates, while in 2011 there were 17%, 8%, 12%, 3%, 25%, and 35% of recovered isolates resistant to 0, 1, 2, 3, 4, and 5 antimicrobials, respectively (Lubbers and Hazlicek, 2013).

Resistance among different classes of antimicrobials has been noted in recent years, especially when studying *M. haemolytica*. Between 2000 and 2009, Portis et al. (2012) reported overall decreases in susceptibility of *M. haemolytica* to danofloxacin, tilmicosin, tulathromycin, enrofloxacin, and florfenicol. High levels of antimicrobial resistance against macrolides (tulathromycin and tilmicosin) and tetracycline (oxytetracycline) have been reported in many studies. Similarly, in a three-year retrospective analysis, Lubbers and Hanzlicek (2013) determined that there were significant coresistance patterns seen in oxytetracycline and tilmicosin, with bacterial isolates resistant to either antimicrobial more likely to be resistant to at least one other antimicrobial. Snyder et al. (2017) examined the prevalence of MDR *M. haemolytica* isolated from stocker cattle at arrival and two weeks after processing when given metaphylaxis with tulathromycin. Of the 169 cattle, 27 were culture positive for *M. haemolytica* at arrival with 1 MDR strain of *M. haemolytica* isolated (Snyder et al., 2017). At second sampling, 366 individual *M. haemolytica* isolated were collected from the cattle with 361 of these isolates classifying as either intermediate or resistant to all macrolides tested (tilmicosin, gamithromycin, and tulathromycin) and the fluoroquinolone enrofloxacin (Snyder et al., 2017).

The significant increase in minimum inhibitory concentrations (MICs) for *M. haemolytica* for tilmicosin and tulathromycin leads to question if the antimicrobials are truly effective treating BRD, as well whether *M. haemolytica* could harbor resistance genes for macrolides that could be transmitted to other respiratory pathogens (Portis et al., 2012; Zaheer et al., 2013).

The transmission of genes amongst bacteria has become a newer topic with research occurring over the last few years, especially for antimicrobial resistance genes associated with resistance to antimicrobials used to treat BRD. Integrative conjugative elements (ICE) have been discovered to transmit resistance genes among BRD pathogens. Integrative conjugative elements are genetic elements that are part of the bacterial chromosome and can be excised from the genome and transferred to other adjacent bacterial microbes (Johnson and Grossman, 2015). ICE*Mh*1 was recently detected in a strain of *M. haemolytica* that carried resistance to aminoglycosides, tetracyclines, and sulfonamides, and shares a high degree of similarity with ICE*Pmul*, encoding eleven resistance genes within two clusters, including tetracyclines, phenicols, sulfonamides, macrolides, or tilmicosin/tulathromycin (Eidam et al., 2013). Not only does this raise questions on how these genes can be transmitted amongst bacteria of the same genus, but also how the genes are transmitted to bacteria of other species and possibly families.

Economic Impact of BRD

The forage-based gains of stocker production are the least expensive and contribute to the cost competitiveness of the beef industry (Peel, 2003). However, the economic impact of BRD on the stocker, backgrounder, or feedlot has been found the most economically important health problem facing these operations (Daniels et al., 1999). Past research indicates BRD associated costs are $750 million annually (Griffin, 1997), with more recent reports documenting economic loss from cattle that succumbed respiratory disease was $907.8 million, or 24.6%, of the total value of nonpredator death losses in cattle and calves (USDA, 2017). Respiratory disease remains an extensive and costly problem for the beef industry, with the deaths alone from BRD associated cases costing over $600 million annually (USDA-APHIS-VS, 2011). When looking into costs of other inputs such as feed and seed, pasture, fencing, labor, and expenses such as antimicrobial treatments, cost of animals, and vaccines/dewormers, the performance from the stocker cattle becomes highly important to the operation's bottom line.

The National Animal Health Monitoring System's (NAHMS) Beef Feedlot 2011 study (2013) reported that approximately 21.2% (2.9 million) of the cattle placed in feedlots were affected by BRD. The Beef Feedlot 2011 study (2013) reports that the average cost for treating a single case of BRD in feedlots with a capacity of 1000-7999 head and feedlots with a capacity of 8000 or more head was $23.40 and $23.90, respectively, which has increased significantly from costs suggested during a similar study in 1999. As well, cost of treatment for the cattle with acute interstitial pneumonia ($21.70/case) was much higher than the treatment of lameness ($13.40/case) and digestive problems ($9.90/case; USDA-APHIS-VS, 2013). Additionally, Brooks et al. (2011) found that when combining backgrounding and finishing phases, cattle that received three or more treatments and cattle defined as "chronics" lost $72.01 and $143.20 more than cattle that were not treated for BRD. With these figures, the estimated cost for treatment of 2.9 million BRD cases is $54.12 million, not including the production losses due to morbidity and mortality (Johnson and Pendell, 2017). Net returns for cattle in operations that never received treatments are significantly higher ($30.08 ± $66.57) compared to cattle that are treated once or more after diagnosis of BRD (range of $-47.79 ± $82.23 for ≥3 treatments through $15.84 ± 67.12 for 1 treatment) (Cernicchiaro et al., 2012). A study performed by Wilson et al.

(2017) also found that when cattle are treated for BRD once, twice, or three or more times, net returns were decreased by $38, $167, and $230 per calf, respectively.

When cattle are treated with multiple doses of antimicrobials, the cost of treatment for BRD cases increases. Brooks et al. (2018) found that treatment costs ($/head) will increase from $0,00, $9.63, $23.62, and $35.71 as the number of treatments increase from 0, 1, 2, and 3 treatments, respectively. Cattle designated as "chronics" (receive all three antimicrobial therapies according to protocol, on feed more than 21 days, and experienced net loss of body weight over preceding 21 days on feed) from this study incurred $35.34/head for treatment (Brooks et al., 2011). The BRD treatment costs from this study were much higher than previous studies (range of $0.00/head to $21.70/head; Edwards, 1996; Fulton et al., 2002).

Gains from stocker cattle who have been treated for BRD decreases with the number of treatments given and duration of sickness. A study performed by Snowder et al. (2006) demonstrated that economic loss associated with lower gains and treatment costs for BRD infection in a 1000-head feedlot was estimated at $13.90/head, not including labor and handling costs. Cernicchiaro et al. (2013) reported ADG of cattle with 0, 1, 2, or 3 or more treatments as 1.47 ± 0.28 kg, 1.36 ± 0.23 kg, 1.30 ± 0.21 kg, and 1.24 ± 0.19 kg, respectively. Additionally, production parameters measured from a wreck pen (denoted as a pen of cattle pulled for BRD treatment) compared to average metrics for similar cattle had 37.04% death loss (0.7% average), 0.66 lb/d ADG (3.78 lb ADG average), 221 days on feed (166 d average), and feed to gain ratio of 27.48 (5.88 average; Cernicchiaro et al., 2013). Not only does this further emphasize the importance of health of the cattle, but the effect on gains and profitability from cattle contracting BRD is detrimental.

BRD influences performance of cattle beyond the feeding phases. On the rail, the carcasses of cattle differ from healthy cattle to those who were sick. Schneider et al. (2009) reports significant differences in BRD incidence on acclimation ADG, overall ADG, final body weight (BW), fat, and marbling. Similarly, Cernicchiaro et al. (2012) noted hot carcass weight (HCW)) decreasing with added number of treatments for each animal with BRD (HCW: zero treatments= 340.89 ± 38.25 kg, ≥3 treatments= 329.54 ± 42.02 kg), in addition to carcasses grading choice or better compared to less than choice (zero treatments: ≥choice= 46.82% vs. less than choice= 53.18%; ≥3 treatments: ≥choice= 27.92% vs. less than choice= 72.08%). Brooks et al. (2011) provided data supporting that carcass characteristics differ between healthy cattle and those diagnosed with BRD.

Conclusion

Newly weaned, unprocessed cattle are at the highest risk for immune system weakening, allowing for sickness to affect the animal. These cattle are typically lightweight with unknown origin and health status. Cattle with these criteria are considered high risk and immunocompromised. This situation provides the opportunity for disease spread among cohorts and the increased likelihood for BRD, the most costly disease in recently weaned calves, despite improvement in management practices, vaccinations, and antimicrobials (Galyean et al., 1999).

Various predisposing factors can lead to BRD in high-risk cattle. Sale barns are the most likely destination for cattle coming from cow-calf producers, regardless of management practices. As well, sale barns can facilitate spread of illness due to multiple stressors such as commingling, nose-to-nose contact, and recent weaning, which can cause compromised immune function. Other factors such as viral infections, processing of cattle, and environmental factors can also affect the cattle's immune status.

Bovine respiratory disease is a complex illness that suppresses the ability of cattle to perform. It has been shown that BRD can have negative consequences on carcass traits, including carcass weight, ribeye area, and marbling (Thomson and White, 2006; Larson, 2005; Gardner et al., 1999; Smith, 1998). With several bacteria endogenous to the nasopharynx of cattle, *M. haemolytica* is one of the most important bacterial pathogens associated with the development of BRD and is frequently isolated from the airway of feedlot and stocker cattle with disease (Fulton et al., 2009; Timsit et al., 2017). Transmission dynamics for this bacterium are not as well known, thus research studying transmission among cohorts could give some insight.

Antimicrobial resistance to different antimicrobial classes is becoming a problematic issue in bacteria that contribute to BRD. With resistance being found in many classes of antimicrobials that have been typically used for treatment of BRD in the past, it is important to ensure that resistance among bacterial pathogens associated with BRD does not continue to become more problematic over time. Management practices, such as decreasing pen size to alleviate the spread of sickness, may have an influence on the growing problem of antimicrobial resistance.

Profitability is always important to producers and managers of stocker and feedlot operations. Not only does the cost of cattle influence profitability, but the number of treatments, labor, land, and gains of animals determine how much return individuals will receive. Determining the differences among profitability of different pen sizes is an area that has not been studied, and the goal for this research is to give a baseline for others to continue to study pen size and the relevance of economic data to producers.

CHAPTER III

ASSESSMENT OF THE EFFECT OF PEN SIZE ON HEALTH, ANTIMICROBIAL USE AND RESISTANCE, AND MANAGEMENT-RELATED COSTS IN STOCKER CATTLE

Objectives

The objectives of this study were: 1) to examine the effect of number of stocker cattle in a receiving pen on BRD morbidity and mortality and on cattle performance; 2) to examine the effect of number of stocker cattle in a receiving pen on antimicrobial use and prevalence of antimicrobial resistance in *Mannheimia haemolytica*; and 3) to evaluate the economic impact of receiving pen size on the profitability of stocker cattle operations.

Materials and Methods

All procedures in this study were approved by the Institutional Animal Care and Use Committee at Mississippi State University (IACUC # 16-604).

Cattle Handling and Management

Due to market constraints at the time the study was conducted, cattle arrived in two loads and were processed upon arrival. Cattle were individually identified, weighed, sale barn tag recorded, ear notched for BVDV-PI testing, vaccinated (Ultrabac® 7 (Zoetis Services LLC., Parsipanny, NJ) and Express® 5 MLV (Boehringer Ingelheim Animal Health USA Inc., Duluth, GA), dewormed (Safe-Guard® Dewormer (Merck Animal Health, Madison, NJ)), and a nasopharyngeal swab collected. The first load of cattle (n=103) arrived on day -8. After processing on day -7, cattle were placed onto pasture with ad libitum hay and grass for 7 days. Cattle were checked daily for signs of BRD or other illness and any that were treated between day -7 and 0 were not enrolled in the study. The second load of cattle (n=137) arrived on day -1 and placed in a separate pasture. On day 0, the cattle were processed, nasopharyngeal swab collected, sorted into pen groups, and moved to pastures. Cattle were placed on rye grass pastures with ad libitum access to mineral (Bovatec Stocker Mineral, Purina Animal Nutrition, Arden Hills, MN). Pen riders trained in identifying BRD signs assessed each pen and evaluated cattle based on clinical signs of BRD, including, but not limited to, depression, anorexia, rapid respiratory rate, cough, or nasal discharge. If cattle were regarded as potential cases, rectal temperature, BRD score (Appendix A), and treatment were recorded. Cattle were returned to pasture after completion of treatment according to standard protocol. All cattle were observed for 60 days for BRD, bloat, footrot, pinkeye, and other diseases that could affect stocker cattle. All pulls and treatments were recorded on treatment record sheets. If an animal sustained an injury or developed a disease not included in the protocol, a veterinarian was called to examine each case and determine the course of action. All cattle that died were taken to CVM Diagnostic Laboratory and submitted for gross necropsy, lung tissue was submitted for aerobic culture and antimicrobial susceptibility testing for cattle with lung pathology consistent with BRD.

Cattle were weighed on day 14, 28,42, and 60. Cattle in each pen were removed individually and did not come into physical contact with other treatment groups on sampling days. Samples were collected and cattle were moved back to the original pasture.

Treatment of Cattle

Treatment for BRD followed a 3-drug regimen (administered in series according to persistence of clinical signs). The first treatment was ceftiofur crystalline-free acid (Excede, Zoetis Services LLC., Parsipanny, NJ) administered as a single subcutaneous injection (SC) in the posterior aspect of the ear where it attaches to the head (base of the ear) to cattle at a dose of 6.6 mg ceftiofur equivalents (CE) body weight (BW). Cattle were assigned a post-treatment interval (PTI) of 7 days during which no additional treatments for BRD were allowed. Cattle which met the criteria for treatment 8 days or longer after ceftiofur treatment were treated with florfenicol (Nuflor, Merck Animal Health, Madison, NJ) by a single SC injection in the neck at a dose of 40 mg/kg body weight. After florfenicol treatment, cattle were assigned a PTI of 3 days. Cattle which met the criteria for treatment 4 days or longer after florfenicol treatment were treated with oxytetracycline (Noromycin 300 LA, Norbrook Inc., Overland Park, KS) by a SC injection in the neck at a dose of 20 mg/kg. No further treatments were administered to cattle with signs of BRD after a third treatment. During the PTI following any treatment, or after the third treatment, cattle with a BRD score of 3 or 4 were examined by a veterinarian to determine whether euthanasia was warranted.

Bacterial Collection

A nasopharyngeal swab was collected from each animal using a 60 cm long guarded swab (Double Guarded Culture Swab, #022964, MWI, Nampa, ID, USA) as previously described (Woolums et al., 2018). Swabs were then transferred into Amie's transport media (Modified Amies Clear Gel, SP130X, Starplex Scientific Inc. Etobicoke, Ontario, Canada). Nasopharyngeal swabs were collected from all cattle upon arrival and on days 14 and 60. All nasopharyngeal swabs were transported to the Mississippi State University Veterinary Diagnostic Center. Within 8 hours of collection, swabs were streaked onto a sheep's blood agar plate via quarter streaking method and placed in an incubator at 37°C plus 5% CO_2. At 24 and 48 hours after incubation, the plates were assessed for colonies with morphology typical of *M. haemolytica*. If more than one colony with typical morphology were found, one bacterial colony was selected using indole, oxidase, and catalase testing to confirm the colony was likely *M. haemolytica* (indole negative, oxidase and catalase positive). Colonies with consistent morphology and positive tests were subcultured onto a sheep's blood agar plate and incubated for 24 hours. If only one typical colony was identified on the primary plate, the colony was subcultured onto a new blood agar plate and indole, oxidase, and catalase testing was conducted on a colony selected after 24 hours of subculture. Pure cultures obtained on the subcultured plate were transferred to 50% glycerol solution and stored at - 80°C until the end of the trial, when all isolates were submitted to the Diagnostic Bacteriology Laboratory at Mississippi State University for antimicrobial susceptibility testing via the TREK Diagnostics Sensititre™ System (TREK, ThermoFisher Scientific Inc.). *M. haemolytica* isolates were defined as resistant to one, two, or three or more antimicrobial classes. Isolates were considered resistant to a class if they displayed resistance to one or more antimicrobials within that class that also had Clinical Laboratory and Standards Institute (CLSI) breakpoints for *M. haemolytica* in BRD. *M. haemolytica* isolates were defined as multidrug resistant (MDR) if they were resistant to three or more antimicrobial classes. Antimicrobials considered with established breakpoints for BRD as defined by the CLSI were ampicillin, ceftiofur, penicillin, danofloxacin, enrofloxacin, florfenicol, gamithromycin, tildipirosin, tilmicosin, tulathromycin, tetracycline, and spectinomycin.

Cost Analysis

Economic impact of pen size was estimated between large and small pen sizes. Production records for cattle were obtained from arrival to sale date to determine general profitability between pens. Records utilized in the analysis were purchase price, pasture costs, antimicrobial costs, labor, vaccines, mineral, fencing, and selling price.

Treatment groups shared incurred expenses and income for the trial in purchase costs, labor, facility use, water, seed planter, and sale of cattle. Differences in costs between treatment groups were calculated for pasture costs (includes fencing, ryegrass seed/ha, fertilizer/ha, seed used/ha, and tank usage), total costs for antimicrobial treatments, tagging equipment, vaccinations, and death loss. Total cost for treatment was calculated by adding each of the costs (pasture costs, antimicrobial treatment costs, tagging equipment, vaccinations, and death loss) and cost for treatment group/animal was calculated.

For this study, retailers that were commercially available to producers were used to determine pasture costs for both treatments, with recommendations from Wheeler Metals (Muskogee, OK) for materials used for corner posts and braces for fencing, seed and fertilizer purchased from local farming co-operative (Oktibbeha County CO-OP) in Starkville, MS, previous purchases for stock tanks and other water supplies from past purchases, and Tractor Supply for all other supplies.

Fencing costs were determined with actual dimensions of pastures which cattle were located for the trial, with measurements for perimeter of pastures, number of gates, feet of barbed wire used for five-strand fence, corners, pasture splits, and t-post spacing were all considered. Fertilizer and seed used were calculated on the hectares for each of the respective pastures based upon the total dimensions of the pastures which cattle were located. Total pasture costs for the large and small treatments were calculated by adding fencing costs, water materials costs, and fertilizer and seed costs. Costs per hectare was determined by taking the total cost per treatment divided by the number of hectares allotted for each treatment.

Antimicrobial treatment costs were determined by using online website. Each antimicrobial used (Excede (ceftiofur), Nuflor (florfenicol), and LA 300 (oxytetracycline)) offered different sized bottles containing either 100, 250, 300, or 500 ml of antimicrobial treatment. Calculations for antimicrobial treatments for each size bottle were calculated based upon the milliliters utilized for each of the treatments in the study and were based on the size of bottle utilized during the study.

Death loss was determined as the cost of calf at time of purchase added to the cost of the calf until it died. The cost of the calf at time of purchase was determined as the expected purchase weight (3% of arrival body weight + arrival body weight) multiplied by the purchase cost. Cost until dead was determined by the cost per hectare per day multiplied by the amount of days between the start of the project and when the calf died. Treatment costs were included in the treatment analysis and were not included in death loss figures.

Statistical Analysis

All analyses were performed in SAS 9.4 (SAS Inst., Inc., Cary, NC). Response variables included morbidity, mortality, DAR, BW, ADG, *M. haemolytica* recovery, resistance to approved antimicrobials for BRD treatment in *M. haemolytica*, and MDR *M. haemolytica*. Fixed effects were treatment (large and small treatment groups), with covariates included in the health and performance models being fever on arrival, and covariates included in the bacterial resistance analyses being fever on arrival and health status (whether animal was treated or not).

For performance and recovery data, main effects of treatment and day, and treatment*day interactions were reported. For all analyses, subject was arrival date nested within treatment, random effect included individual pen that animals were housed within treatments, and pen was the experimental unit. A Fisher's Exact test was used to evaluate significance of covariates within the respective models. Economic data were recorded.

Morbidity, mortality, and DAR were assessed using the GLIMMIX procedure of SAS 9.4 using the Laplace method. Body weights and average daily gain was assessed using the MIXED procedure of SAS 9.4 testing for interactions and main effects, with repeated variable as day and differences adjusted with the Tukey method. Recovery of *M. haemolytica*, antimicrobial resistance, and MDR *M. haemolytica* were assessed using the MIXED procedure of SAS 9.4. Susceptibilities to antimicrobial classes were determined according to CLSI breakpoints. Susceptibilities for antimicrobials used to control BRD with established breakpoints for *M. haemolytica* included ampicillin, ceftiofur, penicillin, danofloxacin, enrofloxacin, florfenicol, gamithromycin, tildipirosin, tilmicosin, tulathromycin, tetracycline, and spectinomycin were described for each bacterium recovered.

Statistical significance was set at $p \leq 0.05$, with tendencies reported at $0.05 < p \geq 0.1$.

Results and Discussion

Cattle Performance

Results for body weight (BW) can be found in Table 4.1. Results for ADG are reported in Table 4.2 for ADG d 1 to 14, 14 to 28, 28 to 42, and 42 to 60. There was no treatment by day interaction for BW ($p = 0.4708$) and no main effect of treatment ($p = 0.5577$). However, there was a main effect for day ($p < 0.001$), with body weights continuing to increase for each sampling period for both treatment groups. There was a tendency for a treatment by day interaction for average daily gain ($p = 0.0592$). On each of the respective sampling days, there were no differences in ADG between the large and small treatment groups. Gains for cattle in both the large and small treatment group were the highest from days 14-28 (large=1.30 ± 0.13 kg/d; small= 1.17 ± 0.14 kg/d). The poorest ADG was within the small treatment groups from days 0-14, gaining 0.19 ± 0.14 kg/d. The lowest ADG for the large treatment group was seen during days 42-60 with cattle gaining 0.27 ± 0.13 kg/d.

Increases in body weights can be expected from growing cattle in any feeding situation. Currently, there are several studies that have evaluated the effect of different numbers of animals within groups on various outcomes, but not within stocker or feedlot realms. A study performed by Gottardo et al. (2005) compared three groups of veal calves based on the number of animals in each group (3, 5, and 7 head) with the same space allowed per head and found that the number of calves per pen did not affect gain, intake, or feed efficiency. Similarly, with this stocker study there was the same amount of space per calf (0.02 ha/head of cattle), and there was no difference for BW or ADG between the two treatments on specific sampling dates. Also, a study with chickens found that stocking rate had no effect on performance parameters of broiler chickens and concluded that high yield per unit could still be achieved at smaller or larger stocking densities (Turkyilmaz, 2008). Based on these two studies and the findings from this pen size study, it is still possible to achieve a similar weight gain and ADG regardless of the number of head placed on pastures while allowing similar hectares per head.

However, a study focusing on the number of ewes and lambs carried at different stocking rates found that ewe live weights and lamb weaning weights decreased as stocking rates increased but noted that the larger number of animals carried at higher stocking rates outperformed animals in smaller groups and resulted in more kilograms of lamb weaned per hectare regardless of poorer performance of each lamb (Sharrow et al., 1981). Although the study focused on performance of sheep at different stocking rates, it also assessed pasture performance at different stocking rates. At the conclusion of this research, pastures stocked with 9.9 ewes/ha were producing 10 to 12% more forage than those stocked at 7.4 and 12.4 ewes/ha (Sharrow et al., 1981). From this study, researchers suggests that there is a minimum as well as a maximum stocking rate that needs to be established to maximize forage production. Similar to this group size study with stocker cattle, the quality of forage was not assessed, but this current study did not assess whether the pastures cattle were housed in produced more forage based on treatment group. Based upon these findings, further studies could be replicated based off of these types of research at the same and larger levels (more pens per treatment, more differences in number of animals in a pen) to determine the true impact of BRD on the performance of cattle in differing stocking densities, to assess maximum sustained forage production and quality, and determine how quality of forage can affect cattle that are or are not treated for BRD.

While this stocker study did not discuss social behavior, it has been shown to influence multiple aspects of livestock production, from smaller animals such as fish to cattle. Jorgensen et al. (1993) found that growth rates among fish that were stocked at medium and high densities were similar yet were markedly depressed compared to fish stocked at the lowest stocking densities. The authors determined that social constraints due to the formation of dominance hierarchies may not have been the prime reason for appetite and growth reduction seen in groups stocked at high densities (Jorgensen et al., 1993). A study performed to assess the influence of different stocking densities on weight gain and behavior on feedlot lambs found that average weight gain was higher for individually penned animals compared to animals found in collective pens, and that the number of animals per group influenced the behavior of confined lambs, which changed the pattern of food intake which could improve weight gain (da Cunha Leme et al., 2013). A study on feeder lambs found that the feeding system for groups of lambs had an effect on growth rates, live-weight at slaughter, carcass weights, dressing percentage, and fat thickness, as well as carcass confirmation scores and fat degree (Carrasco et al., 2009). While these studies are not focusing on stocker production, there has yet to be much research discussing behavior of cattle in larger and smaller groups, and how this may possibly affect performance, social behavior, and grazing activity.

Number of Treatments Affecting Body Weight and ADG

The number of antimicrobial treatments given to cattle throughout the trial influenced BW ($p < 0.0001$). Cattle receiving no antimicrobial treatments gained 15.8 kg and 46.8 kg more than cattle receiving one ($p < 0.0001$) and two or more ($p < 0.0001$) antimicrobial treatments, respectively. Also, cattle receiving one antimicrobial treatment gained 31.1 kg more than cattle receiving two or more antimicrobial treatments ($p < 0.0001$). Average daily gain was also influenced by the number of antimicrobial treatments given to cattle ($p = 0.0021$). Cattle receiving no antimicrobial treatment trended to gain more than cattle treated once with antimicrobials (0.70 kg/d ± 0.07 vs. 0.58 kg/d ± 0.08; $p = 0.0698$) and gained more than cattle receiving two or more antimicrobials (0.70 kg/d ± 0.07 vs. 0.21 kg/d ± 0.16; $p = 0.0014$). Additionally, cattle receiving one antimicrobial treatment gained 0.36 kg/d more than cattle treated two or more times with antimicrobials ($p = 0.0208$).

There is extensive research showing the effects of BRD on performance of cattle. Hubbard et al. (2018) found that ADG of cattle diagnosed with BRD were 0.15 lb/day lower than cattle undiagnosed with BRD. These authors also found that calves with BRD gained an average 64.1 lb less than unaffected calves over the stocker phase (Hubbard et al., 2018). In another study, feeder cattle and cattle treated for BRD had a mean ADG reduction of 0.07 kg/d, which could result in 3-7% daily reduction in performance (Thompson et al., 2006; Theurer et al., 2015a, 2015b). These studies, like this stocker study, show that cattle not treated with antimicrobials are more likely to experience more weight gains in respect to both BW and ADG compared to cattle treated for sickness. Different management strategies have been studied to reduce the impacts of BRD on animal performance, from vaccinations against viral and bacterial agents (Martin et al., 1982; Richeson and Falkner, 2020), deworming strategies (Wagner, 2018), preconditioning (Step et al., 2008; Cole, 1985), and administering metaphylaxis on arrival, to name a few, which have showed promise in decreasing the impacts of BRD related sickness in cattle.

Cattle Health

Fever on Arrival

The median rectal temperature for cattle upon arrival was 39.3°C (102.8°F), with the range 38.1°C-41°C (100.6°F-106.3°F). Elevated temperatures of 40°C (104°F) or greater were noted in 17 of 200 cattle. Fever on arrival had an effect on BRD morbidity and mortality, as cattle arriving with a fever were more likely to be treated for BRD (p=0.0163), but less likely to die (p=0.0242). Out of the 17 cattle that arrived with fever, 58.82% (n=10) were treated for BRD. In contrast, out of the 183 cattle that arrived without a fever, 19.43% (n=55) contracted BRD during the trial. Of the 17 cattle with a fever on arrival, 18% (n=3) died from BRD. Contrastingly, 82% (n=14) cattle died from BRD that did not arrive with a fever.

Similar to this study, Griffin et al. (2018) found that cattle with high fever at arrival had increased BRD morbidity but is not reported among literature why cattle arriving with a fever were less likely to die. The threshold at which fever is defined, however, does vary among literature. For instance, this study as well as Griffin et al. (2018), Woolums et al. (2018), Wagner et al. (2018), Jelinski and Janzen (2019) et al. defined fever as 40°C or higher. However, others defined thresholds for fever ranging from 39.4°C to 39.7°C (Burfeind et al., 2012) or diagnose BRD cases based upon outward signs of BRD rather than fever. Similarly, most stocker or feedlot operations diagnose BRD based upon outward signs. Finding ways to identify a common temperature to define fever, as well as a standard BRD scoring system for identifying cases, is needed to standardize a method that can be used by all.

Morbidity

Results of DAR can be found in Table 3.3. There were no differences between large and small treatment groups for morbidity (p=0.5041) or incidence density (p=0.8397). Overall morbidity totaled 32.5% (65/200), with 34% and 28% of cattle in large and small treatment groups treated for BRD. From day 0 to 7, the greatest number of cattle (n=41) exhibited clinical signs of BRD and were treated, with 48 cattle treated once and 2 cattle receiving a second treatment before day 14. Of the 65 cattle that were treated once, 12 cattle were treated a second time with florfenicol. Out of the 12 cattle that received the second treatment, 5 cattle were treated a third time with oxytetracycline. Incidence density was calculated at 7.28 BRD cases/1,000 calf days, with 8,698 total days at risk being reported.

Respiratory diseases are the leading cause for sickness in feedlot cattle within the United States (Edwards, 2010; Sanderson et al., 2008; Wilson et al., 2017), Australia (Cusack, 2004), Canada (Church and Radostits, 1981; Smith, 1998), and Brazil (Malafaia et al., 2016; Baptista et al., 2017). The Beef Cattle Research Council describes that BRD accounts for 65-80% of the morbidity seen in some feedlots. A West Texas A&M Study also noted that typically morbidity ranges from 20 to 80%, with an average morbidity of 35% (Richeson, 2018). Also, a Brazilian study found that when all sick feedlot cattle were considered (n=13,315 head), BRD was determined to be the principal cause of morbid cases, accounting for 86.9% of all sickness (Baptista et al., 2017). Similarly, a separate Brazilian review assessing mortality cases in feedlots from 2000 to 2017 found that aside from acidosis, the most common disease associated with feedlot deaths was pneumonia (Silva et al., 2020). None of these studies previously mentioned, however, were performed to assess the number of animals in a pen, but rather on a typical feedlot setting. However, this study does fall within the typical morbidity range, relating closely to the average morbidity seen in feedlot cattle of 35% (Richeson, 2018).

Most (n=48) of the BRD cases seen with this study were within the first two weeks of the study, slowly declining to about 1-4 BRD cases and then seeing a slight increase in BRD cases around day 42 with no cases diagnosed and treated after. Richeson (2018) discussed that over 90% of the BRD cases occur before day 42 in high-risk cattle that were received in the West Texas A&M Research Feedlot. While it is not uncommon to have BRD cases typically outside of 7-21 days after receiving, there are many factors that could have affected the pattern of BRD cases seen in this study, such as commingling of the two groups and additional stress of pulling sick cattle from the pens.

Mortality

Mortality tended to be different between large and small treatments (p=0.0744). Overall mortality totaled 5.5%, with all deaths occurring in the large treatment group. Two out of the five cattle receiving all three antimicrobial treatments died during the trial. Out of the eleven cattle that died, four were humanely euthanized. Ten of the cattle that died had bacterial organisms recovered from the lung tissue upon necropsy, with only one that had no bacterial growth recovered. None of the bacterial organisms recovered from the necropsies were *M. haemolytica.* All cattle that died suffered from bronchopneumonia.

In 2006, respiratory disease accounted for 28.7% of all deaths in stocker and feedlot operations (USDA, 2006). Dubrovsky et al. (2019) found mortality attributed to BRD in their study of preweaned dairy calves was 19.3%, with a range of 0 to 27.1%. Richeson (2018) reported an average 5% mortality within stocker and feedlot operations. Additionally, Brazilian feedlots found that BRD was the major cause of mortality among their cattle (Baptista et al., 2017). A 5.5% mortality rate was observed in this study with all deaths were occurring in the large treatment group. These results suggest that the large pen size possibly increased the risk for mortality, which could be due to increased commingling within the large treatment group. However, given the limitation of the small number of pens, the study should be repeated with a larger number of pens in each treatment to confirm this effect.

Mannheimia haemolytica **Recovery and Antimicrobial Resistance**

Results for recovery of *M. haemolytica* can be found in Figure 3.2. Results for MDR *M. haemolytica* can be found in Figure 3.3. Discussion of resistance profiles for individual antimicrobials can be found in Figure 3.4. There was no treatment*day interaction (p=0.4953) for recovery of *M. haemolytica* isolates from cattle. However, there is a main effect of day (p=0.0002) as recovery of *M. haemolytica* was higher on day 0 ($p < 0.0001$) and 14 ($p = 0.189$) compared to day 60, with no difference between recovery on day 0 compared to 14 ($p = 0.3209$). There tended to be a main effect of treatment (p=0.0873), as the large treatment group tended to have more recovery of *M. haemolytica* than the small treatment group. There was no treatment*day interaction (p=0.2863) or main effect of day (p=0.5854) for resistance patterns of *M. haemolytica* isolates, but there was a main effect of treatment (p=0.0179) as there was greater instances of antimicrobial resistance found in the small treatment group compared to the large treatment group. There was no treatment*day interaction (p=0.4562) or main effect of day (p=0.6955) for MDR *M. haemolytica*. However, there was a main effect of treatment (p=0.0405), as MDR *M. haemolytica* were more commonly isolated in the small treatment group compared to large treatment group. There were no differences in resistance to individual antimicrobials among bacterial isolates from healthy cattle and cattle treated for BRD within treatment groups. Resistance to tetracycline was most common, with 16/43 (37%), 14/34 (41%), and 3/8 (38%) *M. haemolytica* isolates demonstrating resistance on days 0, 14, and 60. Recovered bacteria exhibited the least resistance to ampicillin. A *M. haemolytica* isolated on day 14 from one calf in the large group that had been treated once for BRD demonstrated resistance to ceftiofur.

Out of 200, 192, and 189 cattle on trial on days 0, 14, and 60, 127, 109, and 67 bacterial isolates were confirmed *M. haemolytica* isolates. Recovery rates of *M. haemolytica* were 43/127 (34%), 34/109 (31%), and 8/67 (12%), respectively, with *M. haemolytica* prevalence decreasing over time. On day 0, 34/43 *M. haemolytica* isolates were recovered from cattle in the large treatment group. Six of the 43 *M. haemolytica* recovered on day 0 were MDR, with 4 bacteria recovered from cattle randomly assigned to the large treatment group. In the small treatment group, 9/43 bacteria were recovered with 2 bacteria exhibiting MDR on arrival. On day 14, 34 *M. haemolytica* were recovered, with 29 from large treatment group and 5 recovered from the small treatment group. Six bacteria recovered on day 14 and identified as MDR, with 4 recovered from the large treatment and 2 recovered from the small treatment. Eight *M. haemolytica* were isolated form cattle on day 60, with 6 isolated from the large group and 2 isolated from the small group. Only 1 MDR bacterial isolate was recovered on day 60 and this was one of the 2 *M. haemolytica* isolated from the small treatment group.

Over the sampling period, overall *M. haemolytica* prevalence decreased. While the prevalence of cattle shedding *M. haemolytica* in commingled, recently transported groups typically increases over the 2 weeks after arrival (Woolums et al., 2018), in this study a subset of the cattle were received a week before the rest of the cattle. While the day 0 sample was collected at arrival from cattle in both groups, the day 14 sample was collected 21 days after arrival in the first subset. Thus, the peak of *M. haemolytica* shedding could have occurred before the day 14 samples were collected in those cattle, decreasing the overall prevalence at study day 14. However, the decrease in prevalence could have been due to other bacterial species overgrowing *M. haemolytica*. For example, E. coli EC93 uses contact-dependent growth inhibition to inhibit other bacterial species from growing in population (Ruhe, 2013). Additionally, Bavananthasivam et al. (2012) found that *P. multocida* inhibits the growth of *M. haemolytica* by contact- or proximity-dependent mechanisms. Magwood et al. (1969) reported that *M. haemolytica* was isolated irregularly, even when swabbing both the right and left sides of the anterior and posterior nasal meatuses of calves multiple times a day for several days in a row. Timsit et al. (2017) determined that a high proportion of cattle harbored BRD pathogens in the lower airways when the pathogens were not present in the nasal pathogens. Even with knowing how other bacteria affect isolation rates of *M. haemolytica* and the irregularity associated with differing nasal passages, these points were not within the scope of this experiment. This should warrant further studies into determining the bacterial populations within the nasopharynx of cattle housed within differing group sizes, as well as testing both nasal meatuses of cattle to determine differences in bacterial populations.

Snyder et al. (2017) found few (10.1%, 8/79) MDR *M. haemolytica* isolates in cattle sampled by nasopharyngeal swabs at arrival, but 7-10 days later at second sampling high prevalence of resistance was identified (99.2%, 363/366), primarily in macrolide class. Timsit et al. (2017) described high levels of resistance (>70%) against tulathromycin and oxytetracycline in *M. haemolytica* and *P. multocida* isolates. In this study, there was an increase in prevalence of MDR *M. haemolytica* in cattle in the small pen group compared to the large pen group. Perhaps smaller groups of cattle allowed for increased chances of transmission of bacterial isolates harboring resistance genes among cattle.

Similar to Snyder et al. (2017), in previous work Woolums et al. (2018) identified a high prevalence (86%) MDR *M. haemolytica* shedding in a single group of 50 high risk stocker cattle at 14 days after arrival. The difference in the percent of cattle shedding MDR *M. haemolytica* at day 14 between that study and the present study (86% versus 3%) is noteworthy. The difference may have been related to the fact that cattle in the previous study were metaphylactically treated with a long-acting macrolide (tildipirosin) at arrival, while the cattle in the present study did not receive metaphylaxis. Additionally, a 3-day PTI was used in the previous study, while a 7-day PTI was used for ceftiofur, and a 4-day PTI was used for florfenicol, in the present study. Research directly comparing the prevalence of MDR bacterial shedding in cattle receiving or not receiving metaphylaxis, and in cattle treated with antimicrobials following different PTI, will be necessary to confirm the relationship between these practices and MDR prevalence.

Economic Analysis

All analyses for economic data can be found in Table 3.4, with a more detailed description in Table A.4.

Shared Costs

Labor from d 0 to d 60 for four student workers totaled 618.48 hours at $8.25/hour, with a total payout of $5,102.46. Cost per day averaged $85.04/day for all workers. Facilities were utilized for five sampling points over the 60-day trial. Total costs for the facilities used were $1,851.32, with an average cost per workday (n=5) totaling $106.40. Water used totaled $12.00 for the entirety of the trial.

Both treatment groups had the same number of water tanks (n=3) and totaled $1,343.07 in costs. The large treatment group encompassed 30.36 ha, while the small treatment group had 10.1 ha. Fertilizer costs were $281.05, with the large and small treatment groups incurring $8,532.68 and $2,838.61 in fertilizer expenses, respectively. Ryegrass seed costs were $104.51/ha, with the large and small treatment groups totaling $3,172.95 and $1,055.56, respectively. Total fertilizer and seed costs were $11,705.63 for the large treatment and $3,894.16 for the small treatment, with $385.56/ha spent on both sets of pastures.

For this study, labor and sale cost were not divided between treatment groups. When pen riders completed daily checks of cattle, total hours for each day were totaled and calculated at the end of the trial. Because of the utilization of four observers throughout the trial, pairs of pen riders rode through either large or small treatments, alternating daily which pens were rode through, to ensure that pen riders were getting views of all cattle. Therefore, the total labor costs were not split between groups. Future studies are warranted to determine the split costs for each treatment group by using specific individuals for each treatment and one individual recording the times for checks and pulls.

Differentiated Costs

Purchase and Processing

Cattle were purchased at $1.5797 per pound, a total cost of $195,945.99. The large treatment group incurred a total purchase cost of $128,164.33 for 150 steer calves. The average purchase price for the large treatment group was $854.43, with a range of $737.07 - $990.90. the small treatment group had a total purchase cost of $42,839.68. The average purchase price for the small treatment group was $856.79, with a range of $737.07 - $964.86.

A total of sixteen packs of tags were purchased for the cattle before processing. Numbered tags were $26.99/bag, and blank-colored tags were $22.95/bag, each bag holding 25 tags each. A total of $299.64 was incurred for tags in the large treatment group, with 6 bags purchased of both numbered and blank tags, while the small treatment group had $99.88 worth of tags purchased, with 2 bags of each tag used. Costs for Ultrabac 7 and Express 5 were $28.39 (250 ml/50 doses) and $113.99 (50 doses). Treatment costs for the large (n=3 bottles) and small (n=1 bottle) treatment groups for vaccinations totaled $85.17 and $28.39 for Ultrabac 7, and $341.97 and $113.99 for Express 5, respectively. Safeguard dewormer (1 gallon) was used, totaling $195 for large treatment costs and $65 for small treatment costs. In total, processing costs for the large and small treatments were $921.78 and $307.26, respectively, with costs at $6.15/head to process.

Cattle prices are influenced by many factors, including changes in cattle slaughter, supplies of other meat and poultry products, demands for cattle for feeding or grazing, and consumer demands (Schulz, 2015), as well as other factors such as a processing facility fire and facility shutdowns. Purchase costs vary depending on the month that cattle are planned to be purchased. This can be demonstrated in Figure 3.5, where the prices of cattle purchased in Mississippi are tabled over a ten-year production period. Cattle purchased during the spring months, typically March-May, are more likely to bring more at an auction market compared to cattle sold during the fall months, typically August-October. Texas A&M Extension reports that there may be a seasonal consumer demand pattern that cause livestock producers to alter their production patterns to take advantage of market opportunities, such as a fewer number of calves sold during the spring causing an increased demand and price for cattle during these seasons (Davis et al., 2021). The fluctuations in the cattle market are notable during the seasons, but ultimately the differences among producer preferences for calving and times to sell cattle are dependent on each individual producer.

Sell Costs

The total shared expenses that were incurred during the trial was $204,389.13. Cattle were sold in three different groups at an average weight of 706.67 pounds. Group 1 (n=74 head) sold at $158.00/cwt, group 2 (n=61) sold at $132.00/cwt, and group 3 (n=68) sold at $137.00/cwt. After commission, the sale of cattle totaled $197,896.82. The average sell cost for cattle was $974.86/head. In the large treatment group, 139 cattle were sold in May with a total income of $135,505.70. In the small treatment group, 50 cattle were sold with a total income of $48,743.06.

Cattle were weighed as a group upon sale, which is typical in a stocker/backgrounding facility shipping cattle to a feedlot. While the study concluded in March, cattle were sold in May and the weights from each group divided by the total number of animals were used to calculate average weight for the individuals within the respective group. Weights for cattle at the end of the trial were calculated, but not used in the economic analysis. To obtain a price for income between treatment groups, the total number of head that were sold in May was multiplied by the average cost for the cattle that were sold. Because of this, further studies could be used to determine economic evaluation of cattle upon completion of the project.

Fencing Costs

The large treatment incurred a total of $13,927.65 in fencing costs, and small treatment had $11,165.67 in fencing costs. Four fabricated T-braces ($209.31/brace), seven corner posts ($190.00/corner post), and fifteen H-braces ($125.00/brace) were used for the large treatment pastures, with $4,042.24 spent on these supplies. A total of eight fabricated T-braces, four corner posts, and six H-braces were used to create pastures for the small treatment group, totaling $3,184.48. A total of 1086 and 771 studded T-posts (7 ft, 1.25 lb/ft; $5.22/post) were used for the large and small treatment groups, with 43 and 31 rolls of barbed wire (1320 ft/roll, 12.5 gauge; $74.99/roll) used for a five-strand barbed wire fence and one extra bag of T-post clips (50/pack; $4.99/pack) purchased. Total costs for the five-strand barbed wire fence were $8,89.48 for the large treatment group pastures and $6,354.30 for the small treatment group pastures. Incurred costs per hectare for the large and small treatments were $458.75/ha and $1,105.51/ha, respectively. Costs per hectare per day for the large and small treatment groups were $7.65/ha/d and $18.43/ha/d, respectively.

The most noted difference in price occurs when purchasing gates and braces for the small treatment group, which in turn increases the cost per hectare. For each pasture that the cattle were housed in, there were two gates. This would increase the number of gates purchased for the small treatment group to 10 gates compared to only 6 gates needed for the large treatment group. Additionally, there was a substantial increase for braces needed by the small treatment groups, particularly for the fabricated T-braces (one H-brace, one pipe cap, and 4 pipe; custom weld). There was 8 fabricated T-braces needed for the small treatment compared to only 4 needed for the large treatment. This doubled the costs for the fabricated braces for the small treatment, showing that the small treatment group would be more cost intensive on a per hectare basis compared to the large treatment group at a similar stocking density.

Antimicrobial Treatment Costs

During the trial, 51 cattle from the large treatment and 14 cattle from the small treatment were treated at least once. A total of 417 ml and 90 ml of ceftiofur, 366 ml and 30 ml of florfenicol, and 84 ml and 0 ml were given to cattle in the large and small treatment groups, respectively. Bottle sizes for ceftiofur, florfenicol, and oxytetracycline used during the trial were 100 ml, 100 ml, and 250 ml. with costs per bottle at $234.99, $80.71, and $47.99, respectively. Costs per ml for ceftiofur, florfenicol, and oxytetracycline totaled $2.35/ml, $0.81/ml, and $0.19/ml, respectively. Total costs/ml for large and small treatments were $979.91/ml and $211.49/ml for ceftiofur, $295.40/ml and $24.21/ml for florfenicol, and $16.12/ml and $0/ml for oxytetracycline, respectively. Total costs/bottle of antimicrobial for the large and small treatment groups were $1,174.95 (n=5 bottles) and $234.99 (n=1 bottle) for ceftiofur, $322.84 (n=4 bottles) and $80.71 (n=1 bottle) for florfenicol, and $47.99 (n=1 bottle) and $47.99 (n=1 bottle) of oxytetracycline, respectively. Costs of antimicrobial treatment on a per head basis for large and small treatment groups respectively was $9.41/head and $15.11/head for ceftiofur, $26.21/head and $24.21/head for florfenicol, and $3.22/head and $0/head for oxytetracycline, respectively. Total antimicrobial treatment costs for the large and small treatment groups on a per head basis was $39.48/head and $39.32/head, respectively.

Losses from respiratory disease among stocker and feedlot operations accounts for 55% of nonpredator related death loss in cattle and 36% among calves, with a value of $274.84 million in economic losses (USDA, 2017). Antimicrobial treatment costs for stocker and feedlot operations have been increasing through the years. The USDA NAHMS health and health management report (2013) shows that feedlots spend approximately $75 million annually on antimicrobial treatments for cattle, which can be broken down to 16% of cattle in feedlots with over 1000 head capacity incurring antimicrobial costs of $23.60 for each BRD case. This report noted an increase in antimicrobial costs from 1999 to 2011, describing those costs over the twelve-year period increased from $12.59/head to $23.60/head, and suggested that the costs may increase as time progressed. Even though there were no significant differences among treatment groups for BRD occurrence, it can be noticed that the cost of antimicrobial treatment on a per head basis has increased based on the results from the USDA NAHMS report and the conclusion of this research. Based on the USDA NAHMS findings at the feedlot level, the low amount of research on economic impact at the stocker level, and the similarities in antimicrobial treatment protocols between stocker and feedlot operations, it can be concluded that an increase in antimicrobial treatment costs has been noted in the growing phase from 2011 to 2019. Because of this, it can be expected that economic costs of antimicrobial treatments will continue increase with time.

Another recent study assessed the cost effect of three policies in feedlots: 1) using antimicrobials for disease prevention, control, and treatment; 2) using antimicrobials only for treatment of disease; and 3) not using antimicrobials for any reason (Lhermie et al., 2020). This research determined that when modelling a typical U.S. feedlot, the median net revenue loss with moderate disease incidence was $66 and $96 per animal entering the feedlot, for not using antimicrobials to prevent and control diseases, or not using any antimicrobials, respectively (Lhermie et al., 2020). Lhermie et al. (2020) also reported that in the case of no antimicrobial use, this decreased feeder price by 9%, which in turn increased the slaughter cattle price by 6.3%, offsetting the net revenue losses for the feedlot operation. However, the question still returns to whether this practice could be used in an industry perspective. Even though the costs of not treating cattle with antimicrobials are essentially curbed, the thought comes forth of how not treating animals is affecting gains associated with the cattle as well as the health of the cattle going into slaughter, raising concerns for animal welfare and quality of the product going to the rail. Further, a more detailed analysis of inputs and outputs for usage and prohibition of antimicrobials to stocker and feedlot cattle will be needed to assess the effectiveness of this strategy.

Death Loss

Eleven cattle died during the project, all within the large treatment group. No death losses were incurred for the small treatment groups. Purchase cost of cattle that died ranged from $802.16 to $956.73, with an average purchase cost of calf at $865.46. Cattle died within day 3 and 53 of the trial (either natural death or humanely euthanized), with an average date recorded for 18 days on trial. Cattle averaged a purchase weight of 547.9 lbs, with a purchase cost of

$1.5797/lb. When including only fencing costs, dead cattle averaged $999.61/head in losses, with a range of $848.03 to $1,269.21 in losses recorded. Total losses from each of the eleven cattle that died from the large treatment group totaled $10,995.76 when including fencing costs alone, denoting fertilizer and seed costs as shared costs and not included in this analysis. When including all pasture costs (fencing, fertilizer, and seed costs), dead cattle averaged $1,125.31/head in losses, with a range of $891.02 to $1,648.92 in losses recorded. Total losses from each of the eleven cattle that died from the large treatment group totaled $12,378.44 when including fencing, fertilizer, and seed costs.

BRD incidence typically occurs from approximately day 7 to 21 after arrival to a backgrounding facility, but it is not uncommon to have deaths or cattle requiring treatments outside of this date range. Two cattle that were euthanized on days 35 and 53, with one calf dying on day 31. The time these three cattle lasting on the trial did increase the average cost until the animal died and total loss figures. On the other hand, there were cattle that died before day 7 of the trial. However, it is important to note that there was no statistical significance of arrival time affecting BRD incidence.

In a study performed by Blakebrough-Hall et al. in 2020, the average net loss from cattle that died was $1,647.53. In this study, the average costs from BRD related deaths were $1,125.31/head. While losses were lower in this study compared to Blakebrough-Hall et al. (2020), the calculated figures in this study did not include vaccinations, deworming, tagging, or antimicrobial treatment costs, so it is possible that the death loss figures incurred in this study with those figures would be higher and likely compare similarly to the Blakebrough-Hall study. Hunsaker (2020) assessed the economics associated with calf grower operations in the dairy industry to determine that for each 1.0% decrease in mortality, an increase of $14.45/head could be expected. Authors also noted that at a 10% mortality, a margin of $79.63 exists that can be reinvested, and $7.42 exists at 15% mortality (Hunsaker, 2020).

This research investigating two different group numbers showed that mortality tended to be influenced greater in the larger treatment group compared to the smaller treatment group, enhancing the possibility for smaller groups of cattle to have less sick and dead animals compared to larger groups. With the additional costs associated with cattle that die in stocker and feedlot operations, including antimicrobial costs, feed, labor, and other inputs, ways to mitigate death loss are needed. While it can be expected for losses to be incurred at these operations, managing these ill animals on a more individual basis or within smaller pens could be the answer to managing these losses.

Conclusions

Cattle within both large and small treatment groups performed similarly at each of the sampling periods, with the highest ADGs reported at day 14-28 for both groups. Additionally, body weights for cattle continued to increase over time, which remained similar with other research among stocker and feedlot operations as well as in production settings. Still, the weight that is lost during the first two weeks and possibly later in the trial (if external factors, introduction of more cattle, or other stress-inducing conditions occur) could be mitigated by managing the cattle more efficiently. This could be done by reducing the number of animals within a pen, however, because this is a pilot study with such few numbers, those conclusions cannot be defined at this time.

How to keep a healthy immune system in cattle will always be an important factor when discussing ways to mitigate sickness. Better management of cattle prior to auction could possibly produce a healthier calf moving forward through the stocker and feedlot phases. However, there has yet to be any published research within this field, so looking more deeply into managing cattle upon arrival to reduce the impact of stress could be the answer to decreasing the impacts of BRD. While there were no differences in morbidity of cattle among treatments, fever on arrival played an important role in BRD instance, further detailing how important managing cattle prior to sale can be. Additionally, with more chance for external stressors such as pulling stress, commingling stress, and herd hierarchy, there is a possibility for larger groups of cattle increasing the likelihood for more deaths. However, because this tended to be different between groups, it cannot be concluded that smaller groups of cattle are the answer to decreasing the amount of dead cattle and several more replicates should be performed to test this difference.

Cattle shedding *M. haemolytica* was much higher earlier in the stocker period, highlighting the majority of illness occurring in this trial was during the first two weeks. Additionally, antimicrobial resistance and multidrug resistant *M. haemolytica* were more commonly isolated from cattle in smaller groups. This could be due to the greater chance for nose-to-nose contact among smaller groups, allowing for more transmission of bacteria harboring resistance genes. Genotyping was not performed with this study to determine similarities among bacterial populations isolated from pen mates, which could be an addition for future studies that will further define the impacts of cattle group sizes.

Expenses associated with stocker cattle show to be greater than the income received at the end of the stocker phase. Antimicrobial treatment costs alone have increased substantially over time, accounting for $39-40/head in this stud compared to past figures of $14-21/head. Based on this research, elevated costs for fencing for the small treatment group and death losses remaining isolated to the large treatment group influenced the increased costs per head for each.

Specifically for the small treatment group, there were more materials needed to fence five separate pastures, with more gates and braces, compared to the large treatment group fencing three pastures. This increase in price drove the cost per head for fencing higher for the small treatment group, as smaller pasture sizes are more intensive and cost more per hectare. However, the big difference lies within the loss for deaths, as all the deaths occurring in the large group added $10,995.76 ($12,378.44 including fencing, fertilizer, and seed costs) of losses where no death loss occurred in the small treatment group. Because of this offset, the total loss expected per head for the large treatment group was less than the small treatment group. When it comes to economics and the various factors that can affect losses and income for the year, more replicates for this type of study are needed to be able to determine more finite costs for producers.

Because of the nature of a pilot study, financial reasons, as well as other natural means that influence morbidity and performance, statistical significance was not reported for all parameters of interest. However, due to the persistence of BRD and the impacts that it has on the stocker and feedlot operations, further studies are warranted to determine management strategies that can reduce BRD incidence. Because of the novelty of pen size to stocker cattle research and the lower numbers in this pilot study, replications of this research are needed to improve the power of the study and determine if the number of animals in a pen impacts BRD, performance, antimicrobial resistance.

Table 3.1 Effect of pen size on body weights of cattle over a 60-day trial

Item	Treatment[1]			
	Large[3]	SEM	Small[4]	SEM
Body weight, kg [2]				
Initial	232.6 $_a$	3.2	232.4 $_a$	3.5
d 14	236.6 $_b$	3.2	235.2 $_b$	3.5
d 28	255.0 $_c$	3.2	251.8 $_c$	3.5
d 42	266.9 $_d$	3.2	260.9 $_d$	3.5
Final	270.8 $_e$	3.2	269.0 $_e$	3.5

[1] Subscripts that differ are considered different (a, b, c, d, e, f, g, h).
[2] Body weights were collected every 14 days during the trial.
[3] Large: n=150 head of cattle over 3 pens (50 head/pen)
[4] Small: n=50 head of cattle over 5 pens (10 head/pen)

Table 3.2 Effect of pen size on average daily gain of cattle over a 60-day trial

Item	Treatment[1]			
	Large[3]	SEM	Small[4]	SEM
Average daily gain, kg/d [2]				
d 0 to 14	0.17_f	.13	0.14_h	.17
d 14 to 28	1.20_a	.13	1.13_{ab}	.17
d 28 to 42	0.73_c	.13	0.59_{cd}	.17
d 42 to 60	0.16_g	.13	0.52_e	.17

[1] Subscripts that differ are considered different (a, b, c, d, e, f, g, h).
[2] Average daily gains were calculated at each weight sampling period.
[3] Large: n=150 head of cattle over 3 pens (50 head/pen)
[4] Small: n=50 head of cattle over 5 pens (10 head/pen)

Table 3.3 Effect of pen size on days at risk of cattle being assessed for Bovine Respiratory Disease over a 60-day trial

Treatment	lDAR	SEM
Large[1]	2.86	0.14
Small[2]	3.02	0.23

P – value = 0.4387
[1] Large: n=150 head of cattle over 3 pens (50 head/pen)
[2] Small: n=50 head of cattle over 5 pens (10 head/pen)

Table 3.4 Descriptive statistics of the effect of large and small treatment groups on the costs of inputs and outputs during a 60-day trial

Expenses and Income	Shared	Large (n=150)	Small (n=50)
Shared			
Fertilizer and Seed (cost/hectare)	$385.56		
Labor[1]	$5,762.46		
Facility use[2]	$106.40		
Water[3]	$12.00		
Water Troughs	$1,343.07		
Total Shared Costs	**$6,563.93**		
Total Shared Income[4]	**$197,896.82**		
Cost per Treatment Group			
Purchase		$128,164.33	$42,839.68
Total Antimicrobial Treatment		$1,545.78	$363.69
Total Fencing Costs		$13,927.65	$11,165.67
Total Processing		$921.78	$307.26
Death Loss[5]		$12,704.27	$ ---
Total Cost for Treatments		**$156,937.98**	**$54,676.30**
Total Cost for Treatments/head		**$1,046.25**	**$1,093.53**
Total Income for Treatment Groups		**$135,505.70**	**$48,743.06**

[1]Total of 4 student workers, n=698.48 total hours worked
[2]Five working days with an average cost per day of $21.28
[3]Contractual water payments billed quarterly
[4]Total of 203 cattle sold in two truck loads
[5]All deaths were associated with the large treatment group (Pen 1 n=4; Pen 2 n=1; Pen 3 n=6)

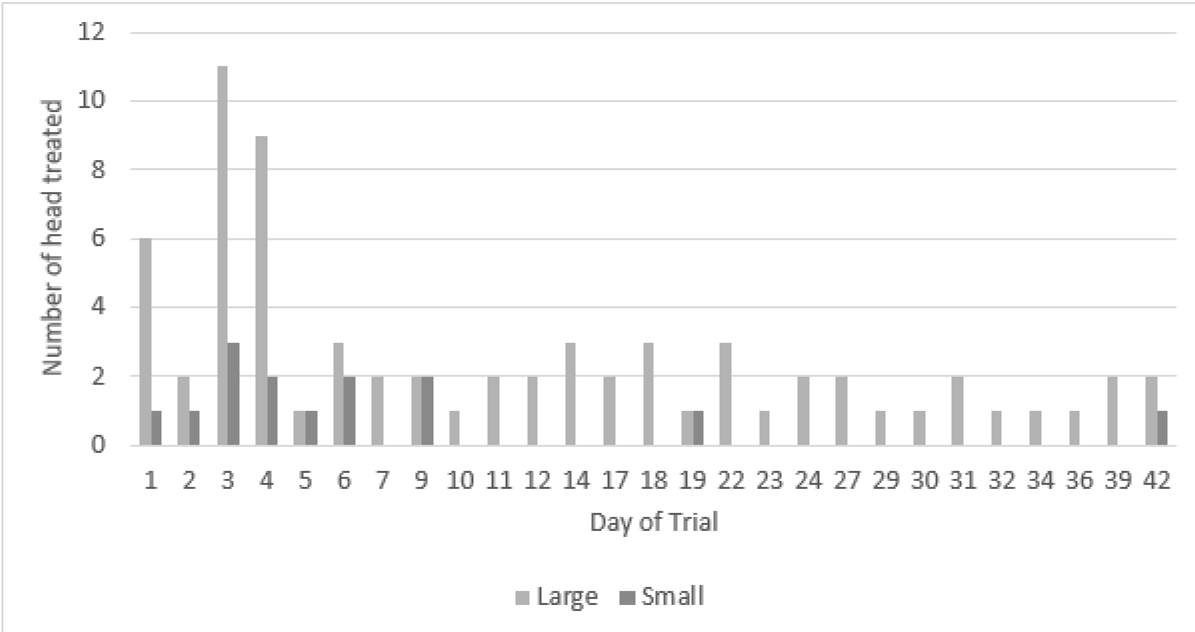

Figure 3.1 Descriptive statistics for the outbreak curve of stocker cattle that succumbed to Bovine Respiratory Disease during a 60-day trial

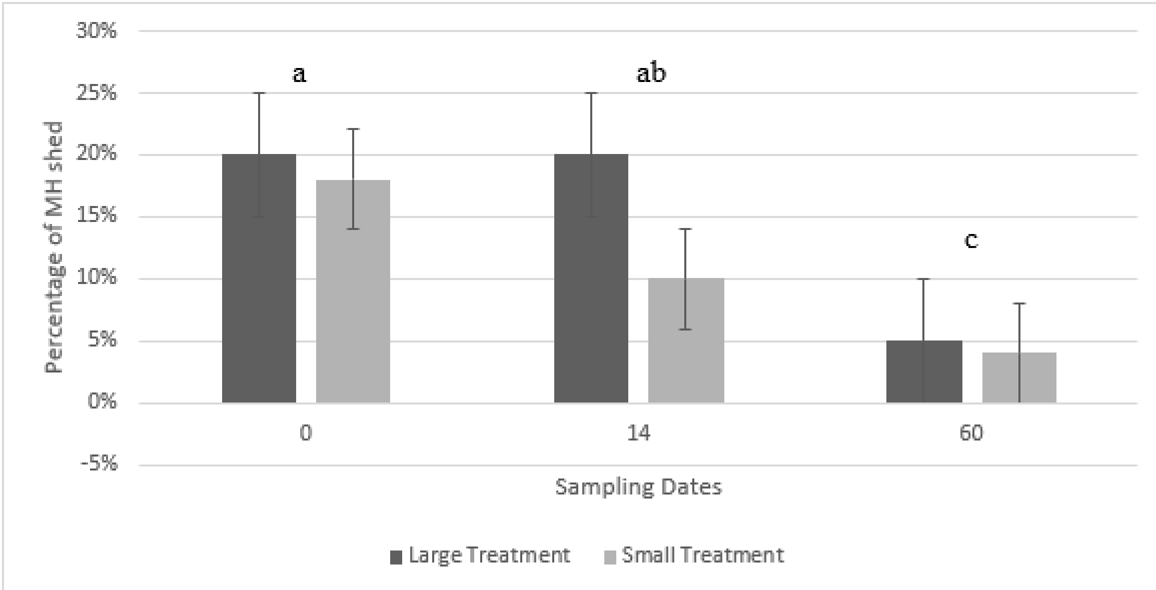

Figure 3.2 Effect of pen size on the percentage of stocker cattle shedding *Mannheimia haemolytica* during a 60-day trial

Subscripts that differ are considered different (a, b, c)
Day 0: Large = 30/150; Small = 9/50
Day 14: Large = 29/142; Small = 5/50
Day 60: Large = 6/139; Small = 2/50

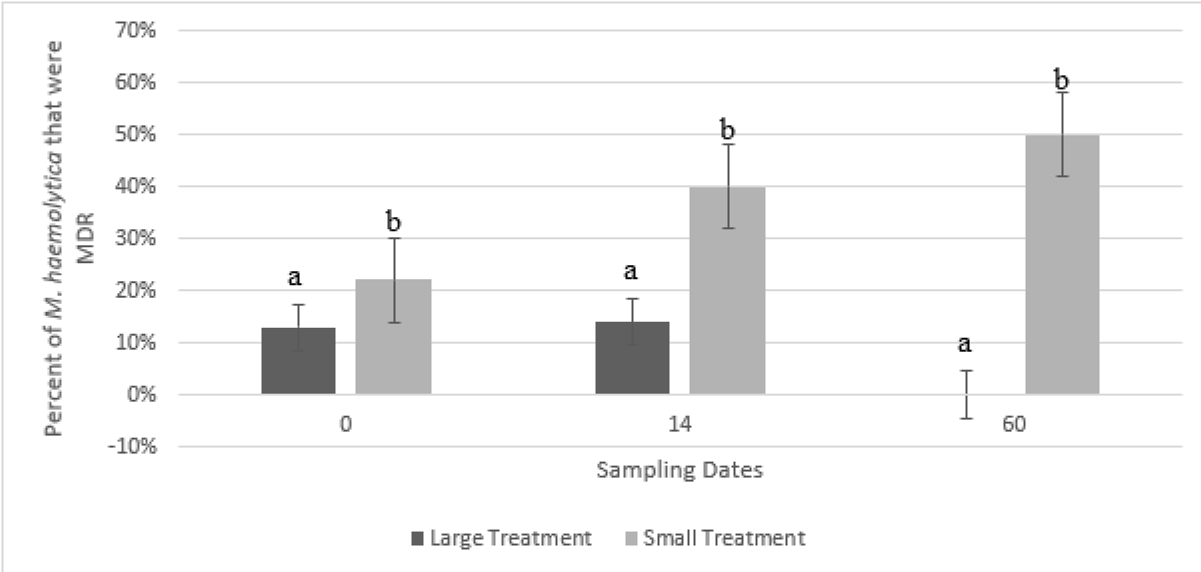

Figure 3.3 Effect of pen size on percentage recovered *Mannheimia haemolytica* that were multidrug resistant during a 60-day trial

Subscripts that differ are considered different (a, b)
Large treatment: day 0 = 4/34 MDR; day 14 = 4/29 MDR; day 60 = 0/6 MDR
Small treatment: day 0 = 2/9 MDR; day 14 = 2/5 MDR; day 60 = 1/2 MDR

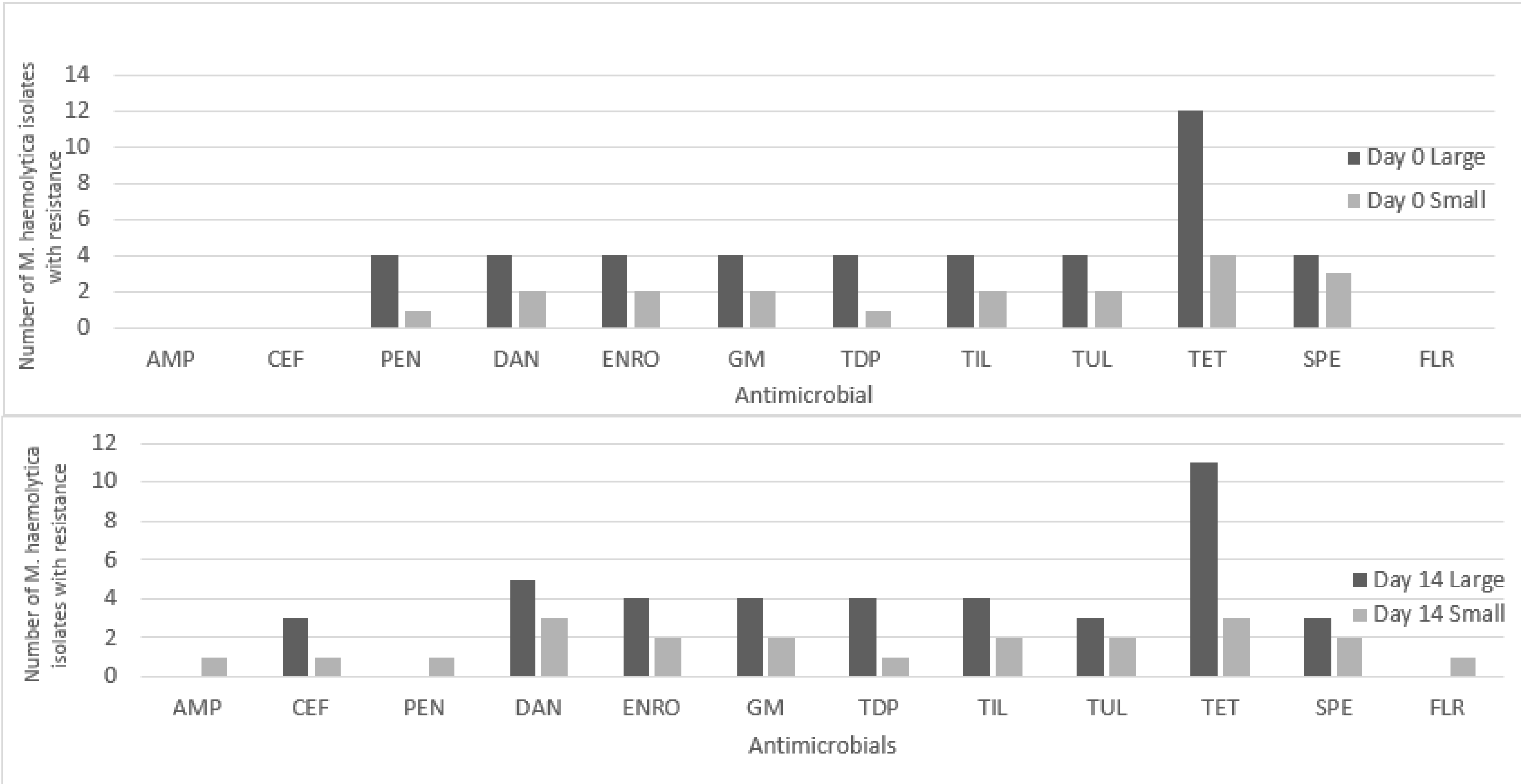

Figure 3.4 Effect of pen size on antimicrobial resistance found antimicrobials for *Mannheimia haemolytica* isolates from stocker cattle over a 60-day trial for days 0, 14, and 60

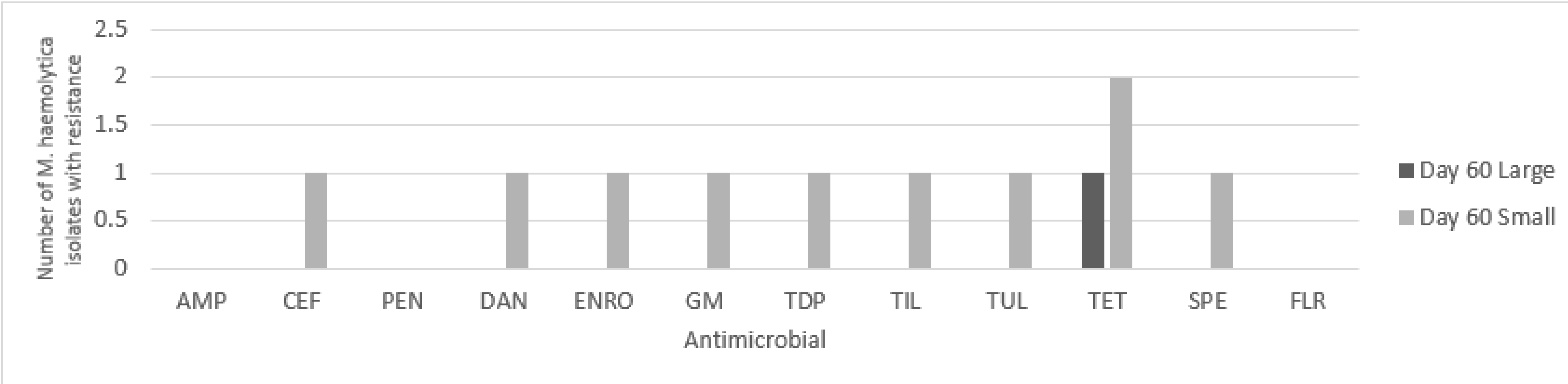

Figure 3.44 (continued)

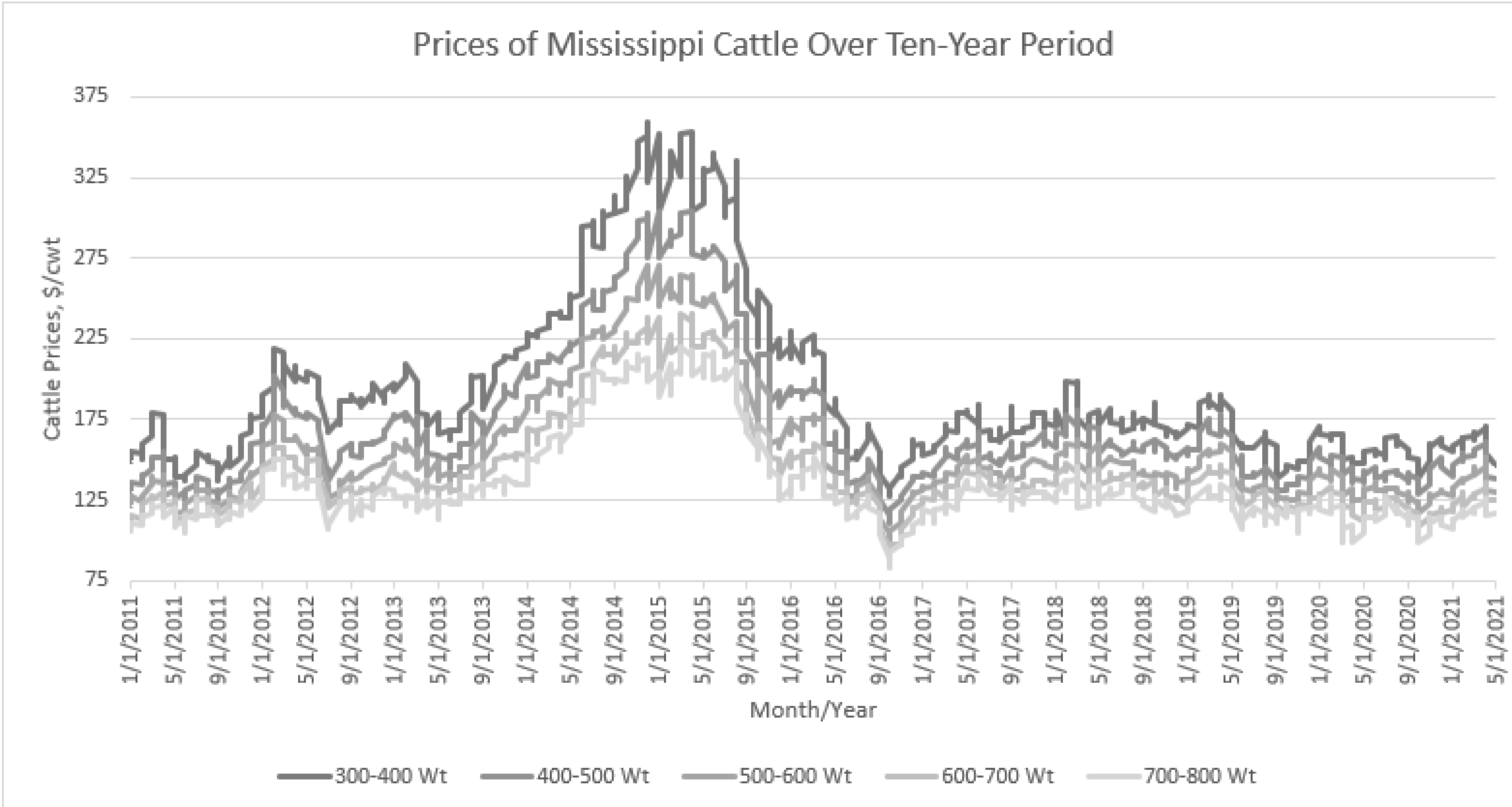

Figure 3.5 Prices of bought cattle in Mississippi over a ten-year production period

REFERENCES

Apley, M. 1997. Antimicrobial therapy of bovine respiratory disease. Veterinary Clinics of North America: Food Animal Practice. 13: 549-574.

Baptista A.L., A.L. Rezende, P.A. Fonseca, R.P. Massi, G.M. Nogueira, L.Q. Magalhães, S.A. Headley, G.L. Menezes, A.A. Alfieri and J.P.E. Saut. 2017. Bovine respiratory disease complex associated mortality and morbidity rates in feedlot cattle from southeastern Brazil. J. Infect. Dev. Ctries. 11:791-799.

Blakebrough-Hall, C., J.P. McMeniman, and L.A. Gonzalez. 2020. An evaluation of economic effects of respiratory disease on animal performance, carcass traits, and economic outcomes in feedlot cattle defined using four BRD diagnosis. Journal of Animal Science. 98.

Booker, C.W., S.M. Abutarbush, P.S. Morley, G.K. Jim, T.J. Pittman, O.C. Schunicht, T. Perrett, B.K. Wildman, R.K. Fenton, P.T. Guichon, and E.D. Janzen. 2008. Microbiological and histopathological findings in cases of fatal bovine respiratory disease of feedlot cattle in western Canada. The Canadian Veterinary Journal. 49:473-481.

Brooks, K.R., K.C. Raper, C.E. Ward, B.P. Holland, C.R. Krehbiel, and D.L. Step. 2011. Economic effects of bovine respiratory disease on feedlot cattle during backgrounding and finishing phases. The Professional Animal Scientist. 27:195-203.

Bryant, L. K., L. J. Perino, D. D. Griffin, A. R. Doster, and T. E. Wittum. 1999. A method for recording pulmonary lesions of beef calves at slaughter, and the association of lesions with average daily gain. Bovine Pract. 33:163–173.

Burfeind, O., V.S. Suthar, and W. Heuwieser. 2012. Effect of heat stress on body temperature in healthy early postpartum dairy cows. Theriogenology. 78:2031-2038.

Cameron, A. and T.A. McAllister. 2016. Antimicrobial usage and resistance in beef production. Journal of Animal Science and Biotechnology. 7:68.

Capik, S.F., B.J. White, B.V. Lubbers, M.D. Apley, D.A. Mosier, R.L. Larson, and R.W. Murray. 2015. Characterization of *Mannheimia haemolytica* in beef calves via nasopharyngeal culture and pulsed-field gel electrophoresis. Journal of Veterinary Diagnostic Investigation. 27: 1-8.

Carrasco, S., G. Ripoll, A. Sanz, J. Álvarez-Rodríguez, B. Panea, R. Revilla, and M. Joy. 2009. Effect of feeding system on growth and carcass characteristics of Churra Tensina light lambs. Livestock Science. 121:56-63.

Cernicchiaro, N., B.J. White, D.G. Renter, A.H. Babcock, L. Kelly, and R. Slattery. 2012. Associations between the distance traveled from sale barns to commercial feedlots in the United States and overall performance, risk of respiratory disease, and cumulative mortality in feeder cattle during 1997 to 2009. J. Anim. Sci. 90:1929-1939.

Church T.L., and Radostits O.M. 1981. A retrospective survey of diseases of feedlot cattle in Alberta. Can. Vet. J. 22:27-30.

Cole, N.A. 1985. Preconditioning calves for the feedlot. Vet Clin Food Anim. 1:401-411.

Confer, A., and D.L. Step. 2009. *Mannheimia haemolytica* and *Pasteurella multocida* induced bovine pneumonia. Current Veterinary Therapy: Food Animal Practice. 5:164-170.

Cozens, D., E. Sutherland, M. Lauder, G. Taylor, C.C. Berry, and R.L. Davies. 2019. Pathogenic *Mannheimia haemolytica* invades differentiated bovine airway epithelial cells. Infect Immun. 87:e00078-19.

Cusack, P. M., N. Mcmeniman, and I. J. Lean. 2003. The medicine and epidemiology of bovine respiratory disease in feedlots. Aust. Vet. J. 81:480-487.

Cusack, P.M.V. 2004. Effect of mass medication with antimicrobials at feedlot entry on the health and growth rate of cattle destined for the Australian domestic market. Aust. Vet. J. 82:154-156.

Czuprynski, C.J., F. Leite, M. Sylte, C. Kuckleburg, R. Schultz, T. Inzana, E. Behling-Kelly, and L. Corbeil. 2004. Complexities of the pathogenesis of Mannheimia haemolytica and Haemophilus somnus infections: Challenges and potential opportunities for prevention? Anim Health Res Rev. 5:277–282.

Da Cunha Leme, T.M., E. A. Lencioni Titto, C. Gonçalves Titto, A. M. F. Pereira, and M. Chiquitelli Neto. 2013. Influence of stocking density on weight gain and behavior of feedlot lambs. Small Ruminant Research. 115:1-6.

Daniels, T.K., J.G.P. Bowman, B. Sowell, and R. Ansotegui. 1999. The effects of metaphylactic injectable antimicrobials on feeding and watering behavior of newly received feedlot calves. MS Thesis, Montana State University-Bozeman.

Davis, E.E., J.D. Sartwelle, and J. Mintert. 2021. Livestock Seasonal Price Variation. Texas A&M Agrilife Extension.

DeRosa, D. C., G. D. Mechor, J. J. Staats, M. M. Chengappa, and T. R. Shryock. 2000. Comparison of Pasteurella spp. simultaneously isolated from nasal and transtracheal swabs from cattle with clinical signs of bovine respiratory disease. J. Clin. Microbiol. 38:327–332.

Dubrovsky, S.A., A.L. Van Eenennaam, B.M. Karle, P.V. Rossitto, T.W. Lehenbauer, and S.S. Aly. 2019. Bovine respiratory disease (BRD) cause-specific and overall mortality in preweaned calves on California dairies: The BRD 10K study. Journal of Dairy Science. 102: 7320-7328.

Duff, G.C., and M.L. Galyean. 2007. BOARD-INVITED REVIEW: Recent advances in management of highly stressed, newly received feedlot cattle. J. Anim. Sci. 85:823-840.

Edwards, A.J. 1996. "Respiratory Diseases of Feedlot Cattle in the Central USA." Bovine Practitioner 30:5-7.

Edwards, T.A. 2010. Control methods for bovine respiratory disease for feedlot cattle. Veterinary Clinics of North America: Food Animal Practice. 26:273-284.

Eidam, C., A. Poehlein, G.B. Michael., K. Kadlec, H. Liesegang, E. Brzuszkiewicz, R. Daniel, M.T. Sweeney, R.W. Murray, J.L. Watts, and S. Schwarz. 2013. Complete genome sequencing of *Mannheimia haemolytica* strain 42547 from a case of bovine respiratory disease. American Society for Microbiology: Genome Announcement. 3:1.

Estima-Silva, P., P.A. Oliveira, F.R.P. Bruhn, H.V. Scheid, L.S. Marques, L.S. Ribeiro, and A.L. Schild. 2020. Causes of death of beef cattle raised in feedlots. Pesquisa Veterinária Brasileira, 40: 333-339.

Fulton, R.W., B.J. Cook, D.L. Step, A.W. Confer, J.T. Saliki, M.E. Payton, L.J. Burge, R.D. Welsh, and K.S. Blood. 2002. "Evaluation of Health Status of Calves and the Impact on Feedlot Performance: Assessment of a Retained Ownership Program for Postweaning Calves." The Canadian Journal of Veterinary Research 66:173-180.

Fulton, R.W., K.S. Blood, R.J. Panciera, M.E. Payton, J.F. Ridpath, A.W. Confer, J.T. Saliki, L.T. Burge, R.D. Welsh, B.J. Johnson, and A. Reck. 2009. Lung pathology and infectious agents in fatal feedlot pneumonias and relationship with mortality, disease onset, and treatments. J. Vet. Diagn. Invest. 21:464-47.

Fulton, R.W., J.D. Neill, J.T. Saliki, C. Landis, L.J. Burge, and M.E. Payton. 2017. Genomic and antigenic characterization of bovine parainfluenza-3 viruses in the United States including modified live virus vaccine (MLV) strains and field strains from cattle. Virus Research. 235:77-81.

Galyean, M., L. Perino, and G. Duff. 1999. Interaction of cattle health/immunity and nutrition. Journal of Animal Science 77:1120–1134.

Gardner, B.A., H.G. Dolezal, L.K. Bryant, F.N. Owens, and R.A. Smith. 1999. Health of finishing steers: effects on performance, carcass traits, and meat tenderness. J. Anim. Sci. 77:3168–3175.

Gioia J., X. Qin, H. Jiang, K. Clinkenbeard, R. Lo, Y. Liu, G.E. Fox, S. Yerrapragada, M.P. McLeod, T.Z. McNeill, L. Hemphill, E. Sodergren, Q. Wang, D.M. Muzny, F.J. Homsi, G.M. Weinstock, and S.K. Highlander. 2006. The genome sequence of Mannheimia haemolytica A1: insights into virulence, natural competence, and Pasteurellaceae phylogeny. J. Bacteriol. 188:7257–7266.

Griffin, C.M., J.A. Scott, B.B. Karisch, A.R. Woolums, J.R. Blanton, R.M. Kaplan, W.B. Epperson, and D.R. Smith. 2018. A randomized controlled trial to test the effect of on-arrival vaccination and deworming on stocker cattle health and growth performance. Bov Pract. 52:26-33.

Griffin D. 1997. Economic impact associated with respiratory disease in beef cattle. Vet. Clin. North Am. Food Anim. Pract. 13:367-377.

Griffin, D. 1998. Feedlot Diseases. Veterinary Clinics of North America: Food Animal Practice. 14:199-231.

Griffin, D. 2006. Antimicrobial metaphylaxis to control respiratory disease. Cattle Production Library CL-606, 1-6.

Griffin, D., M.M. Chengappa, J. Kuszak, and D.S. McVey. 2010. Bacterial pathogens of the bovine respiratory disease complex. Vet Clin. Food Anim. Prac. 26:381-394.

Guardia, S., B. Konsak, S. Combes, F. Levenez, L. Cauquil, J.-F. Guillot, C. Moreau-Vauzelle, M. Lessire, H. Juin, I. Gabriel. 2011. Effects of stocking density on the growth performance and digestive microbiota of broiler chickens. Poultry Science. 90:1878-1889.

Horn, G. W. 2006. Growing cattle on winter wheat pasture: Management and herd health considerations. Vet. Clin. Food Anim. 22:335–356.

Hubbard, K.J., A.R. Woolums, B.B. Karisch, J.R. Blanton, W.B. Epperson, and D.R. Smith. 2018. Analysis of risk factors and production effects following and outbreak of bovine respiratory disease in stocker cattle. The Bovine Practitioner. 52:146-153.

Hunsaker, J. 2020. Economics of calf grower operations in relation to dairy-sourced day-old calf price and feedlot outcomes. MS Thesis. Kansas State University, Manhattan.

Jelinski, M., and E. Janzen. 2019. Research: Bovine Respiratory Disease. Beef Cattle Research Council.

Jeyaseelan, S., S. Sreevatsan, and S.K. Maheswaran. 2002. Role of *Mannheimia haemolytica* leukotoxin in the pathogenesis of bovine pneumonic pasteurellosis. Animal Health Research Reviews. 3:69-82.

Johnson, C. M., and A. D. Grossman. 2015. Integrative and Conjugative Elements (ICEs). What They Do and How They Work. Ann. Rev. Genet. 49:577-601.

Johnson, K.K., and D.L. Pendell. 2017. Market impacts of reducing the prevalence of bovine respiratory disease in United States beef cattle feedlots. Front. Vet. Sci. 4:189.

Jong, A., V. Thomas, S. Simjee, H. Moyaert, F. El Garch, K. Maher, I. Morrissey, P. Butty, U. Klein, H. Marion, D. Rigaut, and M. Valle. 2014. Antimicrobial susceptibility monitoring of respiratory tract pathogens isolated from diseased cattle and pigs across Europe: The VetPath study. Veterinary Microbiology. 172:202-215.

Jorgensen, E.H., J.S. Christiansen, and M. Jobling. 1993. Effects of stocking density on food intake, growth performance and oxygen consumption in Arctic charr (Salvelinus alpinus). Aquaculture. 110:191-204.

Klima, C.L., R. Zaheer, S. R. Cook, C. W. Booker, S. Hendricks, T. W. Alexander, and T. A. McAllister. 2014. Pathogens of bovine respiratory disease in North American feedlots conferring multidrug resistance via integrative conjugative elements. J. Clin. Microbiol. 52:438-448.

Lamm, C.G., B.C. Love, C.R. Krehbiel, N.J. Johnson, and D.L. Step. 2012. Comparison of antemortem antimicrobial treatment regiments to antimicrobial susceptibility patterns of postmortem lung isolates from feedlot cattle with bronchopneumonia. Journal of Veterinary Diagnostic Investigation. 24: 277-282.

Larson, R.L. 2005. Effect of cattle disease on carcass traits. J. Anim. Sci. 83:37–43.

Lhermie, G., P. Sauvage, L.W. Tauer, L.V. Chiu, K. Kanyiamattam, A. Ferchiou, D. Raboisson, H.M. Scott, D.R. Smith, and Y.T. Grohn. 2020. Economic effects of policy options restricting antimicrobial use for high risk cattle placed in U.S. feedlots. PLOS ONE. 15: e0239135.

Lubbers, B.V., and G.A. Hazlicek. 2013. Antimicrobial multidrug resistance and coresistance patterns of Mannheimia haemolytica isolated from bovine respiratory disease cases--- a three-year (2009-2011) retrospective analysis. Journal of Veterinary Diagnostic Investigation. 25: 413-417.

Magstadt, D. R., A. M. Schuler, J. F. Coetzee, A. C. Krull, A. M. O'Conner, V. L. Cooper, and T. J. Engelken. 2018. Treatment history and antimicrobial susceptibility results for Mannheimia haemolytica, Pasteurella multocida, and Histophilus somni isolates from bovine respiratory disease cases submitted to the Iowa State University Veterinary Diagnostic Laboratory from 2013 to 2015. Journal of Veterinary Diagnostic Investigation. 30:99-104.

Magwood, S.E., D.A. Barnum, and R.G. Thomson. 1969. Nasal bacterial flora of calves in healthy and in pneumonia-prone herds. Can J Comp Med. 33:237-243.

Malafaia, P., T.L. Granato, R.M. Costa, V.C.D. Souza, D.F.A. Costa, and C.H. Tokarnia. 2016. Major health problems and their economic impact on beef cattle under two different feedlot systems in Brazil. Pesq. Vet. Bras. 36:837-843.

Martin, S.W., and J.G. Bohac. 1986. The association between serological titers in infectious bovine rhinotracheitis virus, bovine virus diarrhea virus, parainfluenza-3 virus, respiratory syncytial virus and treatment for respiratory disease in Ontario feedlot calves. Can J Vet Res. 50:351–358.

McEwen, S.A., and P.J. Fedorka-Cray. 2002. Antimicrobial use and resistance in animals. Clin Infect Dis. 1:34.

Miles, D.G. 2009. Overview of the North American beef cattle industry and the incidence of bovine respiratory disease (BRD). Published online by Cambridge University Press.

Morck, D.W., J.K. Merrill, B.E. Thorlakson, M.E. Olson, L.V. Tonkinson, and J.W. Costerton. 1993. Prophylatic efficacy of tilmicosin for bovine respiratory tract disease. J. Am. Vet. Med. Assoc. 202:273-277.

NASS, ASB, USDA. Released May 12, 2011. Cattle Death Loss.

Nickell, J.S., and B.J. White. 2010. Metaphylactic antimicrobial therapy for bovine respiratory disease in stocker and feedlot cattle. Vet. Clin. N. Am. Food Anim. Pract. 26:285-301.

Noffsinger, T., and L. Locatelli. 2004. Low-stress cattle handling: An overlooked dimension of management. Proc. Meet. Academy of Veterinary Consultants. 32:65-78.

Noyes R., K.M. Benedict, S.P. Gow, C.W. Booker, S.J. Hannon, T.A. McAllister, and P.S. Morley. 2015. Mannheimia haemolytica in feedlot cattle: prevalence of recovery and associations with antimicrobial use, resistance, and health outcomes. J Vet Intern. Med. 29:705-713.

Panciera, R.J. and A.W. Confer. 2010. Pathogenesis and pathology of bovine pneumonia. Veterinary Clinics of North America: Food Animal Practice. 26:191-214.

Pass, D.A., and R.G. Thompson. 1971. Wide distribution of *Pasteurella haemolytica* type 1 over the nasal mucosa of cattle. Can J Comp Med. 35:181-186.

Peel, D.S. 2003. Beef cattle growing and backgrounding programs. Veterinary Clinics Food Animal Practice 19:65-385.

Peel, D.S. 2020. The effect of market forces on bovine respiratory disease. Vet Clin Food Anim Prac. 36:497-508.

Pinchak, W. E., D. R. Tolleson, M. McCloy, L. J. Hunt, R. J. Gill, R. J. Ansley, and S. J. Bevers. 2004. Morbidity effects on productivity and profitability of stocker cattle grazing in the Southern Plains. Journal of Animal Science. 82:2773–2779.

Portis, E., C. Lindeman, L. Johansen, and G. Stoltman. 2012. A ten-year (2000–2009) study of antimicrobial susceptibility of bacteria that cause bovine respiratory disease complex–*Mannheimia haemolytica*, *Pasteurella multocida*, and *Histophilus somni*–in the United States and Canada. J. Vet. Diagn. Invest. 24:932–944.

Rankins Jr., D.L., and J.W. Prevatt. 2013. Southern Section Interdisciplinary Beef Cattle Symposium: Forage and co-product systems for stockers in the South: have fundamental shifts in markets changed the optimal system? J. Anim. Sci. 91:503-507.

Rhinehart, J.D. and M.H. Poore. 2013. Southern Section Interdisciplinary Beef Cattle Symposium: Opportunities for stocker cattle in the southern United States. J. Anim. Sci. 91:501-502.

Rice J.A., L. Carrasco-Medina, D.C. Hodgins, and P.E. Shewen. 2007. Mannheimia haemolytica and bovine respiratory disease. Anim. Health Res. Rev. 8:117–128.

Richeson, J. 2018. Health and performance during the stocker and feedlot period. Presentation at Florida Beef Cattle Short Course.

Richeson, J.T. and T.R. Falkner. 2020. Bovine Respiratory Disease Vaccination: What is the Effect of Timing? Veterinary Clinics: Food Animal Practice. 36:473-485.

Ruhe, Z.C., D.A. Low, and C.S. Hayes. 2013. Bacterial contact-dependent growth inhibition. Trends in Microbiology. 21:230-237.

Sanderson, M.W., D.A. Dargatz, and B.A. Wagner. 2008. Risk factors for initial respiratory disease in United States' feedlots based on producer-collected daily morbidity counts. Can. Vet. J. 49:373-378.

Schmitz, T.G., C.B. Moss, and A. Schmitz. 2003. Marketing channels compete for U.S. stocker cattle. Journal of Agribusiness. 21: 131-148.

Schneider, M.J., R.G. Tait Jr., W.D. Busby, and J.M. Reecy. 2009. An evaluation of bovine respiratory disease complex in feedlot cattle: impact on performance and carcass traits using treatment records and lung lesion scores. J. Anim. Sci. 87:1821-1827.

Schulz, L. 2015. Seasonal Cattle Price Patterns. Iowa State University Extension and Outreach.

Sharrow, S. H., W. C. Krueger, and F. O. Thetford, Jr. 1981. Effects of Stocking Rate on Sheep and Hill Pasture Performance. Journal of Animal Science. 52; 210–217.

Smith RA. 1998. Impact of disease on feedlot performance: a review. J. Anim. Sci. 76:272–4.

Snowder, G.D., L.D. Van Vleck, L.V. Cundiff, and G.L. Bennett. 2006. Bovine respiratory disease in feedlot cattle: Environmental, genetic, and economic factors. J. Anim. Sci. 84:1999-2008.

Snyder, E., B. Credille, R. Berghaus, and S. Giguère. 2017. Prevalence of multidrug antimicrobial resistance in *Mannheimia haemolytica* isolated from high-risk stocker cattle at arrival and two weeks after processing. J. Anim. Sci. 95:1124-1131.

Step, D.L., T. Engelken, C. Romano, B. Holland, C. Krehbiel, J.C. Johnson, W.L. Bryson, C.M. Tucker, and E.J. Robb. 2007. Evaluation of three antimicrobial regimens as metaphylaxis in stocker calves at high risk of developing bovine respiratory disease. Vet. Ther. 8:136-147.

Sweiger, S.H. and M.D. Nichols. 2010. Control methods for bovine respiratory disease in stocker cattle. Vet Clin Food Anim. 26:261-271.

Taylor, J.D., R.W. Fulton, T.W. Lehenbauer, D.L. Step, and A.W. Confer. 2010. The epidemiology of bovine respiratory disease: what is the evidence for predisposing factors? Canadian Veterinary Journal. 51:1095–1102.

Theurer, M.E., B.J. White, R.L. Larson, and T.C. Schroeder. 2015a. A stochastic model to determine the economic value of changing diagnostic characteristics for identifying bovine respiratory disease. Journal of Animal Science. 93:1–13.

Theurer, M.E., B.J. White, and D.G. Renter. 2015b Optimizing feedlot diagnostic testing strategies using test characteristics, disease prevalence and relative costs of misdiagnosis. Veterinary Clinics of North America Food Animal Practice. 31:483–493.

Thomson, D.U., and B.J. White. 2006. Backgrounding Beef Cattle. Vet. Clin. Food Anim. 22:373-398.

Timsit, E., J. Hallewell, C. Booker, N. Tison, S. Amat, and T.W. Alexander. 2017. Prevalence and antimicrobial susceptibility of *Mannheimia haemolytica*, *Pasteurella multocida*, and *Histophilus somni* isolated from the lower respiratory tract of healthy feedlot cattle and those diagnosed with bovine respiratory disease. Veterinary Microbiology. 208:118-125.

Timsit, E., H. Christensen, N. Bareille, H. Seeers, M. Bisgaard, and S. Assie. 2013. Transmission dynamics of *Mannheimia haemolytica* in newly-received beef bulls at fattening operations. Veterinary Microbiology. 161:295-304.

Turkyilmaz, M.K. 2008. The effect of stocking density on stress reaction in broiler chickens during summer. Turk J Vet Anim Sci. 32:31-36.

USDA–APHIS–VS: National Animal Health Monitoring System Beef Feedlot Study 2011. 2013. Part IV: Health and Health Management on U.S. Feedlots with a Capacity of 1,000 or More Head.

USDA–APHIS–VS: National Animal Health Monitoring System Beef Feedlot Study 2011. 2013. Types and Costs of Respiratory Disease Treatments in U.S. Feedlots. Info Sheet.

USDA-APHIS-VS: National Animal Health Monitoring System Beef Feedlot Study 2015. 2017. Death loss in U.S. cattle and calves due to predator and nonpredator causes, 2015.

Waggoner, J.W., C.P. Mathis, C.A. Loëst, J.E. Sawyer, and F.T. McCollum III. 2005. Impact of preconditioning duration on feedlot performance, carcass characteristics, and profitability of New Mexico Ranch to Rail steers. Proceedings, Western Section, American Society of Animal Science. 56:186-188.

Wagner, R.T. 2018. Assessment of on-arrival vaccination and deworming on health and growth performance in high risk stocker cattle. MS Thesis. Mississippi State University, Starkville.

Wilson B.K., C.J. Richards, D.L. Step, and C.R. Krehbiel. 2017. Beef species symposium: best management practices for newly weaned calves for improved health and well-being. J. Anim. Sci. 95:2170-2182.

Wilson, B.K., D.L. Step, C.L. Maxwell, C.A. Gifford, C.J. Richards, and C.R. Krehbiel. 2017. Effect of bovine respiratory disease during the receiving period on steer finishing performance, efficiency, carcass characteristics, and lung scores. Prof. Anim. Sci. 33:24–36.

Wittum, T. E., N. E. Woollen, L. J. Perino, and E. T. Littledike. 1996. Relationships among treatment for respiratory tract disease, pulmonary lesions evident at slaughter and rate of weight gain in feedlot cattle. J. Am. Vet. Med. Assoc. 209:814–818.

Woolums, A.R., B.B. Karisch, J.G. Fryed, W. Epperson, D.R. Smith, J. Blanton Jr., F. Austin, R. Kaplan, L. Hiott, T. Woodley, S.K. Guptad, C.R. Jackson, and M. McClelland. 2018. Multidrug resistant *Mannheimia haemolytica* isolated from high-risk beef stocker cattle after antimicrobial metaphylaxis and treatment for bovine respiratory disease. Veterinary Microbiology. 221: 143-152.

Zaheer, R., S.R. Cook, C.L. Klima, K. Stanford, T. Alexander, E. Topp, R.R. Read, and T.A. McAllister. 2013. Effect of subtherapeutic vs. therapeutic administration of macrolides on antimicrobial resistance in Mannheimia haemolytica and enterococci isolated from beef cattle. Front. Microbiol. 4:133.

Zecchinon, L., T. Fett, and D. Desmecht. 2005. How Mannheimia haemolytica defeats host defence through a kiss of death mechanism. Vet. Res. 36:133-156.

APPENDIX A

BOVINE RESPIRATORY DISEASE SCORING SYSTEM, BACTERIAL INFECTIONS LIST, AND DESCRIPTION OF ECONOMIC BREAKDOWN

BRD Scoring System

0= Normal

1= Mild BRD including one or more of the following signs:

- elevated respiratory rate for the environmental conditions
- mild to moderate gauntness
- mild depressed attitude: not as alert as expected when viewed from a distance becomes alert when animal sees human observer
- shallow or dry cough

Cattle with a score of 1 may also have cloudy, white, or yellow nasal discharge.

Nasal discharge in the absence of any other abnormalities is not enough for a score of 1.

2 = Moderate BRD including one or more of the following signs:

- mild or moderate depression
  - lethargic, but may look alert when approached
  - head carriage lower than normal, but returns to normal when approached
  - hiding behavior: tends to stay behind other cattle, relative to the observer
- mild to moderate muscle weakness
  - stepping slowly when walking, or mild incoordination
  - droopy ears
- repeated coughing
- moderate gauntness
- breathing with mild to moderately increased abdominal effort

Cattle with a score of 2 may also have:
elevated respiratory rate for environmental conditions
clear, cloudy, white, or yellow nasal discharge.

3 = Severe BRD including one or more of the following signs:

- severe depression or weakness
  - lethargic and does not look more alert when approached
  - low head carriage, does not return to normal when approached
  - does not move away from examiner as expected when approached
  - cross stepping
- Repeated deep cough
- Severe breathing effort

    - open mouth breathing or panting
    - moderately to markedly increased abdominal effort

Cattle with a score of 3 may also have:

elevated respiratory rate for the environmental conditions
clear, cloudy, white, or yellow nasal discharge
and/or moderate to extreme gauntness.

4 = Moribund (near death)

- recumbent and does not rise when approached or directly stimulated

  OR

- standing but does not move unless directly stimulated
    - if the animal moves, it is very weak: drags feet, sways, stumbles, falls down
- eyes may be very sunken, abdomen may be very gaunt

Moribund animals may also have signs described for score of 1, 2, or 3.

Coughing may be heard from animals with any score.

NOTE: sometimes animals near death may act aggressively, trying to charge an observer

Table A.1 Descriptive statistics for the effect of large and small treatment groups on the costs of cattle that died during a 60-day trial

Treatment	Animal ID	Arrival Temp[1]	NmTX[2]	Cause[3]	Organism[4]
Large	147	40.3	1	Bronchopneumonia	*H. somni*
Large	155	38.7	2	Bronchopneumonia	*H. somni*
Large	170	39.7	1	Bronchopneumonia	*P. multocida*
Large	172	39.2	2	Bronchopneumonia	*M. bovis*
Large	175	38.7	1	Bronchopneumonia	*T. pyogenese*
Large	252	39.4	3	Bronchopneumonia	*P. multocida*
Large	274	39.2	2	Bronchopneumonia	*H. somni*
Large	308	40.8	1	Bronchopneumonia	NA
Large	330	41.3	1	Bronchopneumonia	*P. multocida*
Large	33	39.8	1	Bronchopneumonia	*H. somni*
Large	338	39.4	3	Bronchopneumonia	*H. somni*

[1]Arrival Temp= rectal temperature at arrival in Celsius
[2]NmTx= number of treatments that cattle received throughout project until death
[3]Cause= cause of death; each calf that died succumbed death from a type of bronchopneumonia (ex. acute, suppurative, chronic, locally extensive, severe)
[4]Organism= causative organism that infected the lung tissue of dead calf

Table A.2 Descriptive statistics for the effect of large and small treatment groups on associated costs for pasture fencing

Materials		Quantity			
Item	Cost	Large	Small	Large	Small
Tarter Round Plasic Stock Tank, 8'x2', 625 gal	$ 409.99	3	3	$1,229.97	$1,229.97
Heavy Duty Alluminum Float, Standard 6"x12" Float	$22.75	3	3	$68.25	$68.25
Wide Side Mount Kit- Fits Over 2" Lip	$14.95	3	3	$44.85	$44.85
Tater Painted 2 in Tube Gate, 10 ft	$159.99	6	10	$959.94	$1,599.90
OK Brand Premium Barbed Wire, 12.5 guage, 4 pt, 1320'	$74.99	43	31	$3,224.57	$2,324.69
Chicago Heights Steel Tpost Clips, pack of 50	$4.99	1	1	$4.99	$4.99
Studded T-Post, 7 ft, 1.25 lb per foot, includes 5 clips/post, bulk discount-buy 400 get 5% off per post (5.49 original)	$5.22	1086	771	$5,668.92	$4,024.62
H-Brace, 3 1/2, Wheeler Metals	$125.00	15	6	$1,875.00	$750.00
Corner Post Adjustable- 3 1/2, Wheeler Metals	$190.00	7	4	$1,330.00	$760.00
Fabricated T Brace (H brace, cap, 4 pipe), Wheeler Metals	$209.31	4	8	$837.24	$1,674.48
SpeeCo Deluxe Post Driver, Tractor Supply	$26.99	1	1	$26.99	$26.99
Fertilizer, PC Oktibbeha County CO-OP ($11,373.63/40.4686 ha)	$281.05	30.36 ha	10.1 ha	$8,532.68	$2,838.61
Ryegrass seed, Oktibbeha County CO-OP ($4,271.21/40.8686 ha)	$104.51	30.36 ha	10.1 ha	$3,172.95	$1,055.56

Total Cost for Treatments	$26,976.35	$16,402.90
Hectares	10.12	2.02
Total Hectares per Treatment	30.36	10.1
Cost per head	$53.31	$162.40
Cost per hectare per day	$14.81	$27.07

Table A.3 Descriptive statistics for the associated costs of antimicrobials administered to stocker cattle during a 60-day trial

Antimicrobial	Mg/ml	$/bottle	$/ml	Treatment	Group
				Large ($/ml)	Small ($/ml)
Excede	200/100	$234.99	$2.35	$979.91	$211.49
Nuflor	300/100	$80.71	$0.81	$295.40	$24.21
LA 300	300/250	$47.99	$0.19	$16.12	$ ----

Table A.3 (continued)

Bottles	Used	Total $	Bottle
Large	Small	Large	Small
5	1	$1,174.95	$234.99
4	1	$322.84	$80.71
1	1	$47.99	$47.99